U.S. DEPARTMENT OF COMMERCE
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OPERATIONS MANUAL ANAEROBIC SLUDGE DIGESTION

Stevens, Thompson and Runyan, Incorporated

Prepared for
Environmental Protection Agency

February 1976

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The subject of the operation of anaerobic digesters in municipal wastewater treatment plants is presented covering the areas of troubleshooting, general operation, safety, start-up of units, basic theory, sampling and laboratory testing, and other subjects related to day-to-day operation. The intended audience is plant operators who are operating treatment plants with anaerobic digesters. The format is set up to allow individuals to choose the portion of the manual of most interest and use that portion without the necessity of reading all the material sequentially. Information for the contents was obtained by visits to a number of plants, literature research and discussions with experienced digester operators.

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OPERATIONS MANUAL

ANAEROBIC SLUDGE DIGESTION

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U.S. ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

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I. CIRCUMSTANCES LEADING TO THE MORRISTOWN ENCAMPMENT

1779-1780

The direct circumstances which led to the establishment of the military headquarters at Morristown were based on the events in the South, where during September-October of 1779, Vice Admiral Count Charles d'Estaing's squadron was cooperating with the American forces commanded by General Benjamin Lincoln in a joint assault upon Savannah, Georgia.[1] Washington was fully counting and depending on a joint action of d'Estaing's fleet against the British forces in New York City.[2] However, on October 9, 1779, the joint expedition upon Savannah failed, and on October 20 the French fleet departed for the West Indies and France.[3] Unaware of his debacle (during which Count Casimir Pulaski was mortally wounded) and facing Sir Henry Clinton's forces, firmly established in New York City, as well as the problem of the oncoming winter, Washington was forced to consider a winter encampment for his troops.[4]

---

[1] Francis Vinton Greene, *The Revolutionary War and the Military Policy of the United States.* (New York: Charles Scribner's Sons, 1911), pp. 200-05.

[2] John C. Fitzpatrick, ed., *The Writings of George Washington from the Original Manuscript Sources, 1745-1799.* Vol. 17 October 21, 1779-February 9, 1780. (Washington: United States Government Printing Office, 1937), pp. 91, 93-94 and 98. Edmund C. Burnett, ed., *Letters of Members of the Continental Congress*, Vol. IV. January 1 to December 31, 1779. (Washington, D. C.: Published by the Carnegie Institution of Washington, 1928), pp. 513-14 and 518.

[3] Greene, op. cit., p. 205.

[4] Washington to the President of Congress, November 14, 1779. in Fitzpatrick, op. cit., Vol. 17, pp. 105-06.

Except for raids, forays and chance encounters, armies of the time of the American Revolution spent their winters in hibernaculo.[5] By and large, the winter encampment played an important role in the comparatively slow-paced warfare of the 16th, 17th and 18th centuries. Skill in choosing a suitable winter campsite was considered one of the requisite qualities of a good military leader, and involved the assurance not only of sufficient space, but also of good transportation facilities and water and wood supplies, to mention only a few essentials. Such were the problems which concerned General Washington in organizing the winter encampment of 1779-80.

Contrary to the practice which prevailed in the Roman army, by which every encampment was fortified, the winter camps of the 18th century were seldom fortified. [illegible] competent military leaders were careful to take advantage of favorable terrain, so they could quickly draw up their troops in order of battle if necessary.

It was [illegible] who in early [illegible] 1779 [illegible] the task of selecting the quarters for the winter encampment of 1779-80. On November [illegible], 1779, [illegible] favorable location under the [illegible]

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5. The first [illegible] in Sicily took place in 255 B.C. Cf. for this [illegible], Vol. II. (London: Longmans, Green, and Co., 1871), p. 61. The Latin term hibernaculum means "winter quarters." [illegible] the term used by Gaius Julius Caesar.

Scotch Plains, New Jersey.[6] Shortly afterward Lord Stirling expressed his belief that this position was too exposed to enemy attack, expressing his preference for a site near Quibbletown Gap.[7] On November 10, 1779, Colonel James Abeel reported to General Greene that, although he saw no possibilities between Boonton, Baskinridge and Chatham, there existed between First and Second Mountains a "most Beautiful Place for an Incampment";[8] however, when Greene visited the area, he found both sites unsatisfactory.

Washington was looking primarily for a location which would serve the "double purposes of security and subsistence."[9] In his opinion such a location should be free "from the insults of the collected force of the enemy" but also near other American outposts in order to give the location security.[10] In his letter of November 17, 1779 to Maj. Gen. Horatio Gates, Washington stressed that the circumstances and "the abilities of the Quarter Master, Forage Master, and Commy. to support us in provision, forage, and the transportation of them to the places of cantonment" should be considered.[11]

---

6. Biddle to Greene, November 3, 1779, *Correspondence of General Nathanael Greene*, Vol. 3. American Philosophical Society Library, Philadelphia, Pa.

7. *Correspondence of General Nathanael Greene*, Vol. 2, p. 60. American Philosophical Society Library, Philadelphia, Pa.

8. Abeel to Greene, November 10, 1779, in ibid., Vol. 3.

9. Washington to Maj. Gen. Alexander McDougall, November 13, 1779, in Fitzpatrick, op. cit., Vol. 17, p. 101.

10. Washington to Maj. Gen. Horatio Gates, November 16, 1779, in ibid., p. 111.

11. Washington to Gates, November 17, 1779, in ibid., p. 116.

U.S. DEPARTMENT OF COMMERCE
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June 28, 1974

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THURSDAY, DECEMBER 6, 1973
Phone 223-6000

Federal Agency Puts Price on Information

By Thomas Grubisich
Washington Post Staff Writer

INFORMATION is a commodity that can be priced and sold like a pound of butter or a ton of steel.

This is the working philosophy of an unusual government agency called the National Technical Information Service.

The NTIS, an office of the Commerce Department with about [illegible] employees at its headquarters in Springfield, Va., is the Macy's of the information business. In selection, it makes the Government Printing Office look like a small bookstore (NTIS has [illegible] titles in stock, the GPO, [illegible]). It adds [illegible] titles a year and caters to [illegible] customers.

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Sometimes NTIS doesn't. But even that answer could be helpful, perhaps to a scientist who is trying to find out if any of his research is being duplicated by others working in the same area.

Under congressional charter, NTIS can collect any technical information that originates in more than [illegible] government agencies or from thousands of government-sponsored research projects.

Technical information can be so highly specialized that it might have an audience of only three or four people. Some recent titles under the category of biological and medical sciences: "Field Studies Using Wire-Stem Mosquito Bed Nets in Taiwan and Indonesia," "Exploration of Experimentally Produced Fish Peptones for Growth of Microorganisms."

But technical information can cover other, broader subjects, like behavioral sciences, urban technology, environmental pollution and [illegible] that might have an audience of [illegible]. Recently collected reports [illegible] gambling, "The Silent Majority: Neither Simple nor Silent" and "Incentives for Innovation in the Public Schools."

Though NTIS was chartered by Congress to function [illegible] it gets a $1.5 million [illegible] from Congress, but in two years hopes to be self-sustaining. Some of its information-collecting policies would send the average sales manager to the window ledge.

Each year about 20,000 technical reports NTIS gathers—one-third of its collection—are never sold. Yet all these unsold reports must be stocked—at great cost—because they fall in recognized areas of research. And some day somebody might ask for one of them.

Traditionally information hasn't been thought of as a marketable commodity. Libraries acquired great stores of information that anybody could get for the cost of a signature on a card. Governments at all levels distributed all sorts of information free upon request. Free information was viewed as an expression of the democratic process.

The idea that information couldn't be priced even found its way, to some extent, in the business world. A person in Miami can make a long-distance information call to Seattle, and it won't cost him anything. Many companies will supply great quantities of technical information about their products for the asking.

But none of this is really free, says the director of the NTIS, William Knox, a firm believer in putting a price on information. Information costs money to collect and disseminate, he says, and the bill has to turn up somewhere.

The bill for all the information distributed free by government, says Knox, is paid by general revenues, the taxpayers' dollars. Free information from business likewise is paid through general sales, he said.

Knox, a former Exxon and McGraw Hill official, sees some disturbing implications in this time of a continuing knowledge explosion. "It's possible that a lot of inflation in this country may be due to the fact that we are not valuing the price of information. We are not willing to pay. [illegible], if you want this information, you pay for it.

See [illegible], Page B3, Col. 1

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Contrary to the practice which prevailed in the Roman army, by which every encampment was fortified, the winter camps of the 18th century were seldom fortified; however, competent military leaders were careful to take advantage of favorable terrain, so they could quickly draw up their troops in order of battle if necessary.

It was the Quartermaster [illegible], [illegible] [illegible], who in early November 1779 was entrusted by Washington with the task of selecting the quarters for the winter encampment of 1779-80. On November 3, 1779, Col. Clement Biddle found a favorable location under the mountain [illegible] of [illegible] and

---

[5] The first wintering of the Roman Army in Sicily took place in 259 B.C. Cf. for this Wilhelm Ihne, [illegible], Vol. II. (London: Longmans, Green, and Co., 1871), p. 61. The latin term hibernaculum means "winter quarters." This is the term used by Gaius Julius Caesar.

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INTRODUCTION

The purpose of this manual is to satisfy a current need in anaerobic digestion for a guide to digester operation and maintenance for plant operators.

This manual covers three important considerations.

1. It provides a probem solving guide useful in identifying and solving a digester problem and in identifying and eliminating potential problems.

2. It presents routine operational techniques for process control and maintenance.

3. It provides the general background necessary to understand how anaerobic digesters work.

The development of this manual began with contacting and visiting many operators at different plants throughout the country. Their comments have been incorporated in the manual. Use was also made of the vast amounts of literature contributed over the years by scientists and engineers seeking to advance or to explain the state of the art.

Case history examples of problem solving and operational experiences are presented in Part III.

The overall aim is to provide a manual for operators, drawn from experiences of operators, with useful information for the designer and other interested persons as well.

HOW TO USE THIS MANUAL

This manual is not like other books that you have seen on the subject of sludge digestion.

HOW IS IT DIFFERENT?

- You don't have to read page 89 after page 88 if you don't want to.
- If you read only three pages and get a good idea, it's worth it.
- Start where you want to, stop where you want to.

HERE'S HOW IT WORKS––

The manual is divided into four parts and an Appendix. Each has a different use.

- Got a specific problem? Check your plant check list, then go to the Troubleshooting Guides in Part I.
- Want to analyze your digester and see how it compares with others? Look in Part II.
- Are you curious to know what "toxicity" means in a digester? Look in Part III for this title. Other useful topics are also treated in Part III, such as Manpower, Safety, Start-up, Case Histories and Gadgets.
- Want to bone up on what makes a digester "tick"? Look at "The Basics" in Part IV.
- Need more information? Look in Appendix B for reference material. Need worksheets to apply ideas presented to your plant? Look in Appendix H.

HOW TO FIND YOUR WAY AROUND IN THE BOOK––

Parts I, II and III assume that the reader is familiar with the process of anaerobic sludge digestion. Those not completely familiar with the process are encouraged to read and study Part IV, "The Basics."

Page No.	
1-1	**Troubleshooting**–Fourteen separate topics that concern operators are shown in chart form.
2-1	**Plant Check List**–This has space for you to fill in the blanks using information from your own plant and lab records. Use this to see how you compare with the "average." Use it to pick out problem points, places where you might have trouble in the future or where your digester looks pretty good. Follow the references for more information on the subject.
2-6	**Process Operation**–This section has a chart with some of the operation procedures used in some plants and examples of how test results can be used in digester control. References listed here show where to get more information.

Page No.	
3-1	**Potpourri**—(This is a four-bit word meaning "many things are found here.") Personnel, gadgets, and several other topics are stuck back here. Flip through it.
4-1	**The Basics**—Here some of the things you already know are listed along with some things you possibly didn't know. Simplified diagrams show cutaways, illustrations on digesters and pieces of equipment. This will be of most use to new operators. (Note the words in **bold type**, these will be found in the Glossary in the Appendix.)
A-1	**Appendix**--Every manual needs an Appendix. Look here for the glossary, references, metric equivalents and work sheets. Additional literature sources for subjects introduced but not covered in detail are also located here.
inside front cover	**Information Flow Diagram**—A quick guide to the major headings can be used to find the major subject of interest. Then go to the Table of Contents for subtitles or the Reference Key on the inside back cover.
inside back cover	**A Subject Index**, located on the inside back cover is a block diagram that shows where a topic is discussed.

NOW--

You have some idea what's inside. Flip through the pages, get acquainted with how the Troubleshooting Guide works, scan the charts, diagrams and work sheets. Get an idea of what's inside.

FINALLY--

Remember that conditions, arrangement and parameters will vary from plant to plant depending on design, load, waste, etc. The values presented in this manual are typical, but may vary.

See how the contents relate to what you have "in your own backyard." Take a look at the Plant Review Check List starting on page 2-4. Look at your system and fill in the information that represents what your system is and how it's working.

After that is done, go to the section or sections that will help answer the questions raised.

Most of all—don't try to read the manual cover to cover—pick the parts that interest you most.

THE NEXT MOVE IS YOURS--

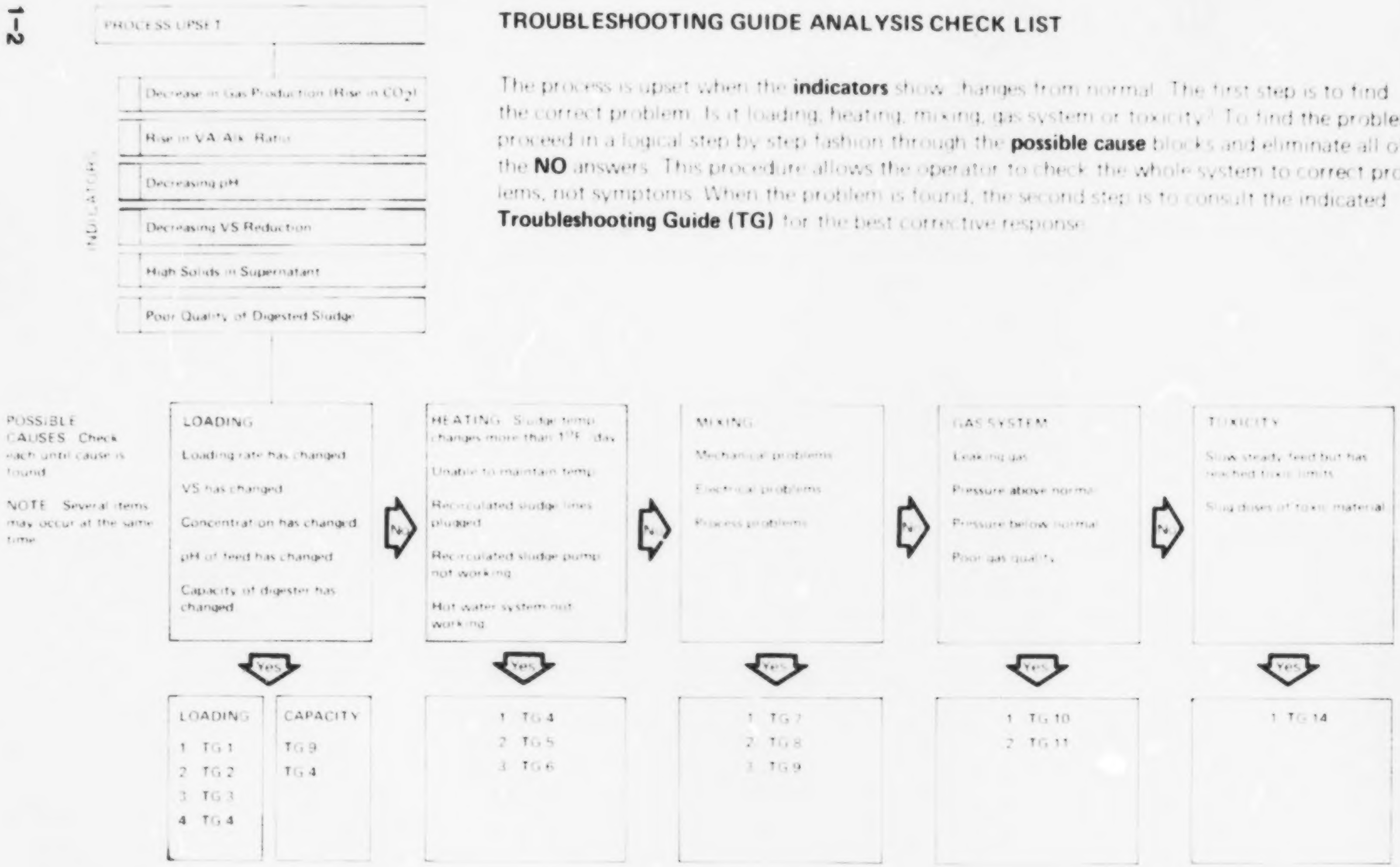
PART 1

TROUBLESHOOTING GUIDES

Troubleshooting Guide Number	Troubleshooting Guide
1	LOADING
2	SUPERNATANT
3	DIGESTED SLUDGE
4	SLUDGE PUMPING AND PIPELINES
5	SLUDGE TEMPERATURE CONTROL USING INTERNAL COILS
6	SLUDGE TEMPERATURE CONTROL USING EXTERNAL HEAT EXCHANGERS
7	SLUDGE MIXING—GAS MIXERS
8	SLUDGE MIXING—MECHANICAL MIXERS
9	SCUM BLANKET
10	DIGESTER GAS SYSTEM
11	DIGESTER COVERS—FIXED
12	DIGESTER COVERS—FLOATING
13	DIGESTER COVERS—GAS HOLDER TYPE
14	TOXICITY

TROUBLESHOOTING GUIDE ANALYSIS CHECK LIST

The process is upset when the **indicators** show changes from normal. The first step is to find the correct problem. Is it loading, heating, mixing, gas system or toxicity? To find the problem, proceed in a logical step by step fashion through the **possible cause** blocks and eliminate all of the **NO** answers. This procedure allows the operator to check the whole system to correct problems, not symptoms. When the problem is found, the second step is to consult the indicated **Troubleshooting Guide (TG)** for the best corrective response.


PROCESS UPSET
INDICATORS
Decrease in Gas Production (Rise in CO_2)
Rise in VA/Alk. Ratio
Decreasing pH
Decreasing VS Reduction
High Solids in Supernatant
Poor Quality of Digested Sludge
POSSIBLE CAUSES. Check each until cause is found.
NOTE. Several items may occur at the same time.
LOADING
Loading rate has changed
VS has changed
Concentration has changed
pH of feed has changed
Capacity of digester has changed
No
HEATING. Sludge temp changes more than 1°F/day
Unable to maintain temp.
Recirculated sludge lines plugged
Recirculated sludge pump not working
Hot water system not working
No
MIXING
Mechanical problems
Electrical problems
Process problems
No
GAS SYSTEM
Leaking gas
Pressure above normal
Pressure below normal
Poor gas quality
No
TOXICITY
Slow steady feed but has reached toxic limits
Slug doses of toxic material
Yes
Yes
Yes
Yes
Yes
LOADING
1. TG 1
2. TG 2
3. TG 3
4. TG 4
CAPACITY
TG 9
TG 4
1. TG 4
2. TG 5
3. TG 6
1. TG 7
2. TG 8
3. TG 9
1. TG 10
2. TG 11
1. TG 14

TROUBLESHOOTING

Troubleshooting begins by knowing the system. The operator needs to know

1. What each part of the system is supposed to do.
2. How each process or piece of equipment operates normally.
3. How to recognize abnormal conditions.
4. What alternatives are available when trouble develops.

Briefly, to recognize when something is bad you must know how it works when no trouble exists.

The purpose of this section is to present a ready and quick operator's reference to process problems and their solutions. They have been drawn from operator's experience in dealing with these problems and from the many authors who have contributed their knowledge.

The Trouble Guides are arranged in columns as explained below.

INDICATORS. The information in this column shows what has been indicated or observed by the operator.

PROBABLE CAUSE. This shows the most likely cause of the indicated upset.

CHECK OR MONITOR. The operator should perform the listed monitoring until the process has recovered. Usually no single indicator tells the whole story.

SOLUTIONS. The operator should perform any of the suggested solutions available to him as indicated.

REFERENCES. This column could be entitled "Help!" The numbers appearing in this column show where in the manual the operator can find additional information.

Reading across the page, follow the numbers. As an example, the number one in the **Solutions** column refers to the number one in the **Indicator** column.

TROUBLESHOOTING GUIDE 1 LOADING

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. A rise in the volatile acid/alkalinity (VA/Alk.) ratio due to hydraulic overload.	1. Overfeeding caused by storm infiltration, accidental overpumping, withdrawing too much sludge.	1. Monitor the following twice daily until problem is corrected: . Volatile acids . Alkalinity . Temperature	1. If ratio increases to 0.3: a. Add seed sludge from secondary digester (or) b. Decrease sludge withdrawal rate to keep seed sludge in digester (and/or) c. Extend mixing time. d. Check sludge temperatures closely and control heating if needed.	2-27, 2-22 4-23 2-10 3-14 3-33 3-42 4-11 4-18
2. A rise in volatile acid/alkalinity ratio due to organic overload.	2. Discharge of industrial waste or increase in septic tank sludge to the plant.	2. Monitor sludge pumping volume, amount of volatile solids in feed sludge.	2. If ratio increases to 0.3: a. Add secondary seed sludge (if available). b. Increase mixing time. c. Decrease bottom sludge withdrawal. d. Check temperature and hold heating at rate to maintain even temperature.	
3. If VA/Alk. ratio rises to 0.5, the concentration of CO_2 in the gas starts to increase.	3. See 1 and 2.	3a. Waste gas burner. b. Gas analyzer.	3. Continue 1b, 1c and 1d as above and starting adding lime or other caustic solution using the volatile acids to calculate the amount.	2-23
4. If ratio rises to 0.8, the pH will start to drop and CO_2 will have increased to the point (42-45%) that no burnable gas is obtained.	4. See 1 and 2.	4a. Monitor as indicated above. b. Hydrogen sulfide (rotten egg) odor. c. Rancid butter odor.	4a. Add lime or other caustic solution. b. Decrease loading to less than 0.01 lb. vol. solids/cu.ft./day until ratio drops to 0.5 or below.	2-23 2-33 3-21 3-34 TG14
5. Meter temporarily out or never installed.			5. Install some type of measuring indicator and attach a cord to the floating cover so that the end can indicate the distance the dome travels when pumping in and not removing supernatant. Calculate the amount pumped in a 24-hour period by this method. Volume computed by the inch or by the foot.	

TROUBLESHOOTING GUIDE 2 SUPERNATANT

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Foam observed in supernatant from single stage or primary tank.	1a. Scum blanket breaking up. b. Excessive gas recirculation. Loading at approximately 0.4 lb. vol.solids/cu.ft./day will produce natural mixing.	1a. Check condition of scum blanket. b. Volatile solids loading ratio.	1a. Normal condition but should stop withdrawing supernatant if possible. b. This condition may indicate an organic overload in digester, making it necessary to slow down feeding.	2-16 4-8
2. Lumps and particles of scum in supernatant from single stage or primary tank.	2a. Scum blanket breaking up caused by excessive mixing or excessive gas production. b. Scum blanket too thick.	2a. Visual observation through window in digester cover. (Unusual increase in gas production also an indicator.) b. Depth of scum by measuring through thief hole or in gap beside floating cover.	2a. Decrease mixing time. Readjust sludge feed. Add more seed sludge. Add lime or other caustic. b. See TG 9, "Scum Blanket."	
3. Supernatant is a gray or brown color from single stage or primary tank.	3a. Inadequate stratification, raw sludge laying in pockets in the tank. b. Digestion time is too short. Sludge concentration is too low or: digester capacity is reduced due to grit and scum layers. c. Digester ecological balance is upset. d. Overloading digester. See TG 1, "Loading."	3a. Check mixing—may be undermixed. Take samples at various depths to detect pockets of undigested sludge. Check temperature gradient in the digester. b. Probe digester to determine grit deposits. c. CO_2 content, compare gas production to amount of volatile solids being fed. Gas production should average 7-12 cu.ft./day/lb.volatile solids destroyed.	3a. Increase mixing or increase frequency of feeding or increase recirculation. b. Readjust feed concentration. Increase mixing or clean out digester. c. Reduce feed rate by diverting to another digester or by some other means increase detention time. d. See alternatives in sections on digester feeding.	2-19

(Continued Next Page)

TROUBLESHOOTING GUIDE 2 SUPERNATANT (Cont.)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
4. Supernatant has a sour odor from either primary or secondary digester.	4a. The pH of digester is too low. b. Overloaded digester ("rotten egg odor"). c. Toxic load (rancid butter odor).	4a. pH of supernatant should be 6.8. b. See TG 1, "Loading." c. See TG 14, "Toxicity."	4a. Add lime or other caustic. b. See TG 1, "Loading." c. See TG 14, "Toxicity."	TG 1 TG 14
5. The SS solids in supernatant returning to process is too high, causing plant upsets.	5a. Excessive mixing and not enough settling time. b. Supernatant draw-off point not at same level as supernatant layer. c. Raw sludge feed point too close to supernatant draw-off line. d. Not withdrawing enough digested sludge.	5a. Put 10-20 liters in glass carboy and observe separation pattern. b. Locate stratum of supernatant by sampling at different depths. c. Determine volatile solids content. Should be close to value found in well mixed sludge and much lower than raw sludge. d. Compare feed and withdrawal rates—check volatile solids to see if sludge is well-digested.	5a. Allow longer periods for settling before withdrawing supernatant. b. Adjust tank operating level or draw-off pipe to get into stratum c. Schedule pipe revision for soonest possible time when digester can be dewatered. d. Increase digested sludge withdrawal rates. CAUTION: Withdrawal should not exceed 5% of digester volume per day. e. No solution, due to poor settling sludge such as primary-activated sludge mixture.	

TROUBLESHOOTING GUIDE 3 DIGESTED SLUDGE

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Gray or brown color from bottom of primary or secondary tank.	1a. Improper digestion. b. Short-circuiting, insufficient mixing.	1a. Layers of unmixed sludge in tank bottom. b. Raw sludge feed point too close to drawoff.	1a. See TG 7 and 8, "Sludge Mixing." b. Change feed point either by external valve or pipe arrangement or revise internally when tank is empty.	TG 7 TG 8
2. Sour odor.	2a. pH of digester is too low. b. Second stage of digestion is retarded. c. Overloaded digester.	2a. Check pH at different levels. b. Check CO_2 content of gas. c. Check ratio of volatile solids added to primary digester.	2a. Add lime. b. Let digester rest. c. See TG 1.	TG 1
3. Bottom sludge too watery or disposal point too thin.	3a. Short-circuiting. b. Excessive mixing.	3a. Draw-off line open to Supernatant Zone. b. Take sample and check how it concentrates in setting vessel.	3a. Change to bottom draw–off line. b. Shut off mixing for 24-48 hrs. before drawing sludge.	
4. Digester full of well-digested sludge and supernatant SS are high.	4a. Not withdrawing enough digested sludge.	4a. Check process indicators. All should be near normal values. Check withdrawal records and compare to feed records.	4a. Increase digested sludge withdrawal to dewatering or disposal. Withdrawal should not exceed 5% of digester volume per day.	4-8 4-18
5. Complete lack of biological activity.	5a. Highly toxic waste such as metals or bacteriocide.	5a. Gas production (or lack of). b. Analyze sample by spectrophotometer or chemical means. (May need commercial lab.)	5a. Empty contents. Be sure to get necessary approvals as required.	

TROUBLESHOOTING GUIDE 4 SLUDGE PUMPING AND PIPELINES

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Sludge concentration below normal in raw sludge sample.	1. Sludge bridging or coning, allowing excess water to be pumped.	1a. Total solids or visual sample. b. Pump discharge pressure lower than normal due to less resistance in line. c. Rising solids in the clarifier.	1. Use water or air to break up raw sludge by attaching a 15' length of pipe to an air hose or to a non-potable water source, then direct the stream into the built-up sludge. Adjust raw sludge pump cycle. If the cause is coning in a digester, several options are available. See item 2 below.	2-7
2. Sludge concentration below normal in sludge from bottom of digester.	2. Sludge coning, allowing lighter solids to be pulled into pump suction.	2. Total solids test or visual observation.	2a. "Bump" the pump 2 or 3 times by starting and stopping. b. Use whatever means available to pump digester contents back through the withdrawal line. c. If available, attach a water hose to the pump suction line and force water through it. (Water source must be nonpotable.) *CAUTION: Run this for no more than 2 or 3 min. to avoid diluting the digester.*	
3. Pump suction and discharge pressures erratic. Pump makes unusual sounds.	3a. Sand, grease or debris plugging suction line. b. Grease from scum pit plugging line.	3a. Pump suction and discharge pressure. b. Pump suction and discharge pressure	3a. Backflush the line with heated digester sludge. b. Use mechanical cleaner. c. Apply water pressure. *CAUTION: Do not exceed working line pressure.* d. Add approx. 3 lb./100 gal. water of trisodium phosphate (TSP) or commercial degreasers. (Most convenient method is to fill scum pit to a volume equal to the line, add TSP or other chemical, then admit to the line and let stand for an hour.)	

TROUBLESHOOTING GUIDE 5 SLUDGE TEMPERATURE CONTROL USING INTERNAL COILS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Low water feed rate to heat exchanger.	1a. Air lock in line. b. Valve partially closed.	1. Inlet and outlet meter readings lower than normal but equal.	1a. Bleed air relief valve. b. Upstream valve may be partially closed.	2-13 4-14
2. Normal feed rate into the heat exchanger but low feed rate out of it.	2a. Faulty meter. b. Leak in heat transfer pipes.	2. Higher inlet meter reading than outlet reading on the water system.	2a. Check by interchanging inlet and outlet meters. b. May require emptying digester to fix.	
3. Boiler burner not firing on digester gas.	3a. Low gas pressure. b. Unburnable gas.	3a. Check for leak in system. b. Check for process problems.	3a. Locate and repair. b. Follow solutions listed in TG 1, "Loading."	
4. Low heat loss between inlet and outlet water.	4. Check for coating on tubes.	4. Temperature gauges on inlet and outlet lines read about the same.	4. Remove coating on the outside of the water tubes which will require draining tank if tubes are internal.	
5. Too high temperature.	5. Solids caked on the outside of the heat exchanger tubing.	5. Temperature records.	5a. Remove coating, may require draining tank. b. Control water temperature to 130 deg. F. maximum.	
6. Coating on inside of heat exchanger piping.	6. Too high temperature.	6. Temperature records.	6a. May be controlled by adding chemicals to boiler make-up water. b. May have to be removed by rodding out lines.	

TROUBLESHOOTING GUIDE 6 SLUDGE TEMPERATURE CONTROL USING EXTERNAL HEAT EXCHANGERS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Low rate of sludge fed through the exchanger.	1a. High temperature override shuts pump down to prevent caking of sludge on the exchanger. b. Check high temperature circuit tied in with hot water heater to assure that it is cutting off at the correct temperature.	1. Low pressure and higher water temperatures.	1a. Open closed valve on pump. b. Check and remove obstruction in the sludge pump. c. Check for and remove obstruction in heat exchanger (spiral type exchangers can be dewatered and opened fairly easily).	2-13 3-14 4-11
2. Recirculation pump not running; power circuits O.K.	2. Temperature override in circuit to prevent pumping too hot water through tubes.	2. Visual check, no pressure on sludge line.	2a. Allow system to cool off. b. Check temperature control circuits.	
3. Sludge temperature is falling and cannot be maintained at normal level.	3a. Sludge is plugging heat exchanger. b. Sludge recirculation line is partially or completely plugged. c. Inadequate mixing.	3a. Check inlet and outlet pressure or exchanger. b. Check pump inlet and outlet pressure. c. Check temperature profile in digester.	3a. Open heat exchanger and clean. b. See TG 4, "Line Plugging." c. Increase mixing time.	
4. Sludge temperature is rising.	4. Temperature controller is not working properly.	4. Check water temperature and controller setting.	4. If over 120 deg. F., reduce temperature. Repair or replace controller.	
5. Temperature readings not accurate.	5. Probes have electrical short or separation internally.	5. Compare with thermometer known to be accurate.	5. Leave probe connected to read-out device, immerse in bucket of water at approximate digester temperature with thermometer in it. Compare readings. (Replace probe if bad, if O.K., see problems above for checking heating system.)	
6. Unable to maintain temperature.	6. Hydraulic overloading.	6. Incoming sludge concentration.	6. See TG 1	

TROUBLESHOOTING GUIDE 7 SLUDGE MIXING—GAS MIXERS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Compressor running hot and/or noisy.	1a. Low oil level. b. High ambient temperature.	1. Visual or audible observation, or by feeling of the unit.	1a. Check oil level in the compressor. b. Check for excessive ambient temperature, provide cover and/or ventilation if necessary. c. Check compressor for excessive wear.	2-12 4-14 2-21
2. Gas feed lines plugging.	2a. Lack of flow through gas line. b. Debris in gas lines.	2. Identify low temperature of gas feed pipes or low pressure in the manometer.	2a. Flush out with water. b. Clean feed lines and/or valves. c. Give thorough service when tank is drained for inspection.	
3. Mixers not operable.	3. Mechanical or electrical problem.	3. Rate of volatile loading to digester.	3. Natural gas evolution will cause mixing if loading is held at 0.3-0.5 lb. volatile solids per cu.ft. per day. *Closer monitoring will be necessary to prevent process upset (See TG 1, "Loading").*	

TROUBLESHOOTING GUIDE 8 SLUDGE MIXING–MECHANICAL MIXERS

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Corrosion of exposed parts by weather and/or corrosive sewage gas.	1. Lack of paint or other protection	1. Note presence of rust, corrosion, or bare exposed metal.	1a. Construction of protective structure. b. Preparation and painting of surfaces.	2-12 4-14 2-21
2. Gear reducer wear.	2a. Lack of proper lubrication. b. Poor alignment of equipment.	2. Excessive motor amperage, excessive noise and vibration, evidence of shaft wear.	2a. Verify correct type and amount of lubrication from manufacturer's literature. b. Correct imbalances caused by accumulation of material on the internal moving parts.	See item 5 below.
3. Shaft seal leaking.	3. Packing dried out or worn.	3. Evidence of gas leakage when checked by soap solution or evident odor of gas.	3a. Follow manufacturer's instructions for repacking. b. Replace packing any time the tank is empty if it is not possible when unit is operating.	
4. Wear on internal parts.	4. Grit or misalignment.	4. Visual observation when tank is empty, compare with manufacturer's drawings for original size. Motor amperage will also go down as moving parts are worn away and get smaller.	4. Replace or rebuild–experience will determine the frequency of this operation.	
5. Imbalance of internal parts because of accumulation of debris on the moving parts (large-diameter impellers or turbines would be affected most).	5. Poor comminution and/or screening.	5. Vibration, heating of motor, excessive amperage, noise.	5a. Reverse direction of mixer if it has this feature. b. Stop and start alternately. c. Open inspection hole and visually inspect. d. Draw down tank and clean moving parts.	
6. Power source interruption.	6. High ambient temperature.	6. Excessive amperage, corroded power connections, overheating causing circuits to kick out.	6. Protect motor by covering with ventilator housing.	

TROUBLESHOOTING GUIDE 9 SCUM BLANKET

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Rolling movement is slight or absent.	1a. Mixer is off. b. Inadequate mixing time. c. Scum blanket is too thick.	1a. Mixer switch or timer. c. Measure blanket thickness.	1a. May be normal if mixers are set on a timer. If not and mixers should be operating, check for malfunction. b. Consider increasing the mixing time. c. See items 4 and 5.	2-12, 2-21 3-39 4-8
2. Dry and cracked scum blanket. (Open digesters.)	2. Lack of recirculation, combination of grease and hair.	2. Visually measure scum depth.	2. Recycle thin sludge with portable pump (with explosive-proof motor).	
3. Scum blanket is too high.	3. Supernatant overflow line is plugged.	3a. Check gas pressure, it may be above normal or relief valve may be venting to atmosphere. b. See 1a above.	3a. Lower contents through bottom drawoff then rod supernatant line to clear plugging. b. Increase mixing time or break-up blanket by some other physical means.	See item 4 below.
4. Scum blanket is too thick.	4. Lack of mixing, high grease content.	4. Probe blanket for thickness through thief hole or in gap beside floating cover.	4a. Break up blanket by using mixers. b. Use sludge recirculation pumps and discharge above the blanket. c. Use Sanfax or Digest-aide to soften blanket. d. Break up blanket physically with pole. e. Tank modification.	
5. Draft tube mixers not moving surface adequately.	5. Scum blanket too high and allowing thin sludge to travel under it.	5. Rolling movement on sludge surface.	5a. Lower sludge level to 3-4" above top of tube allowing thick material to be pulled into tube—continue for 24-48 hours. b. Reverse direction (if possible).	

TROUBLESHOOTING GUIDE 10 DIGESTER GAS SYSTEM

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Gas is leaking through pressure relief valve (PRV) on roof.	1. Valve not seating properly or is stuck open.	1. Check the manometer to see if digester gas pressure is normal.	1. Remove PRV cover and move weight holder until it seats properly. Install new ring if needed. Rotate a few times for good seating.	
2. Manometer shows digester gas pressure is above normal.	2a. Obstruction or water in main burner gas line.	2a. If all use points are operating and normal, then check for a waste gas line restriction or a plugged or stuck safety device.	2a. Purge with air, drain condensate traps, check for low spots. *CAUTION: Care must be taken not to force air into digester.*	
	b. Digester PRV is stuck shut.	b. Gas is not escaping as it should.	b. Remove PRV cover and manually open valve, clean valve seat.	
	c. Waste gas burner line pressure control valve is closed.	c. Gas meters show excess gas is being produced, but not going to waste gas burner.	c. See 1a and also relevel floating cover if gas escapes around dome due to tilting.	
3. Manometer shows digester gas pressure below normal.	3a. Too fast withdrawal causing a vacuum inside digester.	3a. Check vacuum breaker to be sure it is operating properly.	3a. Stop supernatant discharge and close off all gas outlets from digester until pressure returns to normal.	
	b. Adding too much lime.	b. Sudden increase in CO_2 in digester gas.	b. Stop addition of lime and increase mixing.	
4. Frozen PRV valve.	4. Winter conditions.	4. Remove valve cover and inspect PRV.	4. Possible remedies are: a. Mixture of salt and grease applied to seat ring. b. Place vented barrel over valve with an explosionproof light bulb inside.	3-35 4-16
5. Pressure regulating valve not opening as pressure increases.	5a. Inflexible diaphram.	5. Isolate valve and open cover.	5a. If no leaks are found (using soap solution) diaphram may be lubricated and softened using neats-foot oil.	4-16
	b. Ruptured diaphram.		b. Ruptured diaphram would require replacement.	
6. Yellow gas flame from waste gas burner.	6. Poor quality gas with a high CO_2 content.	6. Check CO_2, content will be higher than normal.	6. Check concentration of sludge feed—may be too dilute. If so, increase sludge concentration.	

(Continued Next Page)

TROUBLESHOOTING GUIDE 10 DIGESTER GAS SYSTEM (Cont.)

INDICATORS/OBSERVATIONS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
7. Gas flame lower than usual	7a. High gas usage in plant.	7a. Check gas production rate against gas usage.	7a. This may be normal.	
	b. Gas leak from digester piping or safety devices.	b. Check gas collection and distribution system, starting at digester main collection point.	b. Check for escaping gas, when found, isolate and repair.	
	c. Low gas production due to process problems.	c. See TG 1, "Loading."	c. See TG 1, "Loading."	
8. Waste gas burner not lit.	8a. Pilot flame not burning.	8a. Pilot line pressure at waste gas burner.	8a. Relight if there is pressure.	
	b. Obstruction or water in pilot gas line.	b. See 8a.	b. Purge with air and check for low spots in line if there is no pressure.	
	c. Obstruction or water in main waste gas line.	c. Waste gas pressure control valve.	c. Drain condensate traps, check for low spots, purge with air pressure. *(Care must be taken not to force air into digester.)*	
	d. Pressure control valve closed.	d. See 8c.	d. Open valve & verify that setting will allow valve to open when pressure is about ¼" water column above all other use point pressures.	
9. Gas meter failure (propeller or lobe type).	9a. Debris in line.	9a. Condition of gas line.	9a. Flush with water, isolating digester and working from digester toward points of usage.	
	b. Mechanical failure.	b. Fouled or worn parts.	b. Wash with kerosene or replace worn parts.	
10. Gas meter failure (bellows type).	10a. Inflexible diaphram.	10. Isolate valve and open cover.	10a. If no leaks are found (using soap solution) diaphram may be lubricated and softened using neats-foot oil.	
	b. Ruptured diaphram.		b. Ruptured diaphram. c. Metal guides may need to be replaced if corroded.	
11. Manometer leaking or not reading accurately.	11a. Leak in gas line to manometer.	11a. Inspect for leaks.	11a. Tighten fittings or replace corroded or damaged line.	
	b. Line plugged.	b. Disconnect and note flow, check for gas flow.	b. Rod out or use water pressure to clean.	

(NOTE: Replace with proper liquid, some use special oil, mercury or water.)

TROUBLESHOOTING GUIDE 11 DIGESTER COVERS–FIXED

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Gas pressure higher than normal during freezing weather.	1a. Supernatant line plugged.	1a. Supernatant overflow lines.	1a. Check every two hours during freezing conditions, inject steam, protect line from weather by covering and insulating overflow box.	2-11 3-35
	b. Pressure relief valve stuck or closed.	b. Weights on pressure relief valve.	b. If freezing is a problem, apply light grease layer impregnated with rock salt.	
2. Gas pressure lower than normal.	2a. Pressure relief valve or other pressure control devices stuck open.	2a. Pressure relief valve and devices.	2a. Manually operate vacuum relief and remove corrosion if present and interfering with operation.	
	b. Gas line or hose leaking.	b. Gas line and/or hose.	b. Repair as needed.	
3. Leaks around metal covers.	3. Anchor bolts pulled loose and/or sealing material moved or cracking.	3. Concrete broken around anchors, tie downs bent, sealing materials displaced.	3. Repair concrete with fast sealing concrete repair material. New tie downs may have to be welded onto old ones and re-drilled. *Tanks should be drained and well ventilated for this procedure.* New sealant material should be applied to leaking area using thiakol or other material with durable plasticity.	Fig. 3-15
4. Suspected gas leaking through concrete cover.	4. Freezing and thawing causing widening of construction cracks.	4. Apply soap solutions to suspected area and check for bubbles.	4. If this is a serious problem, drain tank, clean cracks and repair with thiakol or concrete sealers. *Tanks should be drained and well ventilated for this procedure.*	3-15

"Note Items 1 and 2 of "Covers–Fixed" and No. 2 "Covers–Floating" also apply to "Covers–Gas Holder Type."

TROUBLESHOOTING GUIDE 12 DIGESTER COVERS–FLOATING

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Cover tilting, little or no scum around the edges.	1a. Weight distributed unevenly.	1a. Location of weights.	1a. If moveable ballast or weights are provided, move them around until the cover is level. If no weights are provided, use a minimal number of sand bags to cause cover to level up. (Note: pressure relief valves may need to be reset if significant amounts of weight are ac	2-11
	b. Water from condensation or rain water collecting on top of metal cover in one location.	b. Check around the edges of the metal cover. (Some covers with insulating wooden roofs have inspection holes for this purpose.)	b. Use siphon or other means to remove the water. Repair roof if leaks in the roof are contributing to the water problem.	
2. Cover tilting, heavy thick scum accumulating around edges.	2a. In one area, causing excess drag.	2a. Probe with a stick or some other method to determine the condition of the scum.	2a. Use chemicals or degreasing agents such as Digest-aide or Sanfax to soften the scum, then hose down with water. Continue on regular basis every two to three months or more frequently if needed.	
	b. Guides or rollers out of adjustment.	b. Distance between guides or rollers and the wall.	b. Soften up the scum (as in 2a) and readjust rollers for guides so that skirt doesn't rub on the walls.	
	c. Rollers or guides broken.	c. Determine the normal position if the suspected broken part is covered by sludge. Verify correct location using manufacturer's information and/or prints if necessary.	c. Drain tank if necessary taking care as cover lowers to corbels not to allow it to bind or come down unevenly. It may be necessary to use a crane or jacks in order to prevent structural damage with this case.	3-15
3. Freezing problems in PRV.	4. See TG 11, item 1.	4. See TG 11, item 1.	4. See TG 11, item 1.	3-35

"Note Items 1 and 2 of "Covers–Fixed" and No. 2 "Covers–Floating" also apply to "Covers–Gas Holder Type."

TROUBLESHOOTING GUIDE 13 DIGESTER COVERS–GAS HOLDER TYPE

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Cover guides and/or rollers causing cover to bind.	1. Scum accumulation restricting travel.	1. Check scum accumulation and verify the amounts.	1. See TG 12, "Covers Floating," item 1.	4-15
2. Cover binding even though rollers and guides are free.	2. Internal guide or guy wires are binding or damaged (some covers are built like umbrellas with guides attached to the center column).	2. Lower down to corbels. Open hatch and using breathing apparatus and explosionproof light, if possible, inspect from the top. If cover will not go all the way down, it may be necessary to secure in one position with a crane or by other means to prevent skirt damage to sidewalls.	2. Drain and repair, holding the cover in a fixed position if necessary.	3-15
3. Cover tilting, heavy thick scum accumulating around edges.	3a. In one area causing excess drag.	3a. Probe with a stick or some other method to determine the condition of the scum.	3a. Use chemicals or degreasing agents such as Digest-aide or Sanfax to soften the scum, then hose down with water. Continue on regular basis every two to three months or more frequently if needed.	
	b. Guides or rollers out of adjustment.	b. Distance between guides or rollers and the wall.	b. Soften up the scum (as in 3a) readjust rollers for guides so that skirt doesn't rub on walls.	
4. Gas pressure higher than normal during freezing weather.	4a. Supernatant line plugged.	4a. Supernatant overflow lines.	4a. Check every two hours during freezing conditions and inject steam. Protect line from weather by covering and insulating overflow box.	
	b. Pressure relief stuck or closed.	b. Weights on pressure relief valve.	b. If freezing is a problem, apply light grease layer impregnated with rock salt.	
5. Gas pressure lower than normal.	5a. Pressure relief valve or other pressure control devices stuck open.	5a. Pressure relief valve and devices.	5a. Manually operate vacuum relief and remove corrosion if present and interfering with operation.	
	b. Gas line or hose leaking.	b. Gas line and/or hose.	b. Repair as needed.	

"Note Items 1 and 2 of "Covers–Fixed" and No. 2 "Covers–Floating" also apply to "Covers–Gas Holder Type."

TROUBLESHOOTING GUIDE 14 TOXICITY

INDICATORS	PROBABLE CAUSE	CHECK OR MONITOR	SOLUTIONS	REFERENCES
1. Heavy metals a. VA/Alk increases b. pH drops c. Gas production decreases d. Odor of Butyric Acid (rancid butter).	1. Industrial discharges.	1a. Use a silver/silver sulfide electrode to measure pS (Values greater than 14.0 indicate inhibitory concentrations.) b. Use atomic absorption to identify specific metals.	1. Use any or combination of the following: a. Solids recycle. b. Liquid dilution. c. Decrease feed concentration. d. Precipitate heavy metals with a sulfur compound. Be sure pH in digester is greater than 7.0.	3-23
2. Sulfides	2a. Discharge from metallurgical industries. b. Anaerobic activity in sewers or clarifiers.	2a. Industrial wastes at source. b. Flat sewers or inadequate sludge pumping.	2a. Dilution. b. Use iron salts to precipitate sulfides. c. Containment and slow feeding. d. Institute source control program for industrial wastes.	3-23
3. Ammonia Toxicity	3a. Industrial discharges. b. Organic overload. c. Over-correcting a pH problem.	3a. Wastes from industries handling nitrogenous products. b. Pounds volatile solids/day in feed.	3a. Dilution and solids recycle. b. Decrease feed if possible.	3-23
4. Alkali and Alkaline earth salts: Sodium Potassium Calcium Magnesium	4a. Industrial wastes. b. Over-correcting a pH problem.	4a. Wastes from industries handling industrial chemicals, fertilizer, etc. b. Alkalinity and specific constituent amounts.	4a. Use an antagonistic compound. b. Recycle from bottom of secondary to primary digester at 50% of feed rate.	3-22

PART 2

DIGESTER OPERATION

PLANT REVIEW

DIGESTER EQUIPMENT OPERATION

DIGESTER OPERATION

CHEMICALS USED IN DIGESTER CONTROL

PLANT REVIEW

The key to successful operation is knowing the system and being able to look back and evaluate its performance. This can best be done with a check list which allows the operator:

1. To classify and evaluate performance.

2. To identify problems or potential problems. For example, is it an equipment or a process problem?

3. To become familiar with the process.

A sample check list is presented on the following pages which represents a typical plant. Blank check lists are located in Appendix H which should be used for your plant.

WHAT DOES THE PLANT REVIEW CHECK LIST DO?

Part I of the Plant Review Check List classifies the process, identifies support equipment, compares equipment performance and serves as a guide for evaluating overall performance. This information will help to determine adequacy of equipment. Questions to ask are:

1. Is the equipment being used properly as designed?

2. Is the equipment over or underdesigned?

3. Is the equipment adequately controlled?

4. Is there too much down time resulting in excessive cost or too many man-hours?

Part II is used to evaluate process operation and to identify potential problems. The first column lists operating parameters and control tests with ranges commonly found in accepted practice. The operator should compare actual plant values with the above. Where significant differences are found, closer investigation may be needed to pinpoint the real cause.

HOW TO USE THE CHECK LIST FOR REVIEW

The first step is to learn what pieces of equipment are in the process, how they are tied together and what is their expected performance. This can be done by:

1. Using the design drawings.

2. Using the plant's O & M manual.

3. Physically tracing out the individual systems, noting locations of piping, valves and equipment.

It is suggested that the operator draw a simple one-line diagram of his system similar to the example shown in Figure 2-1.

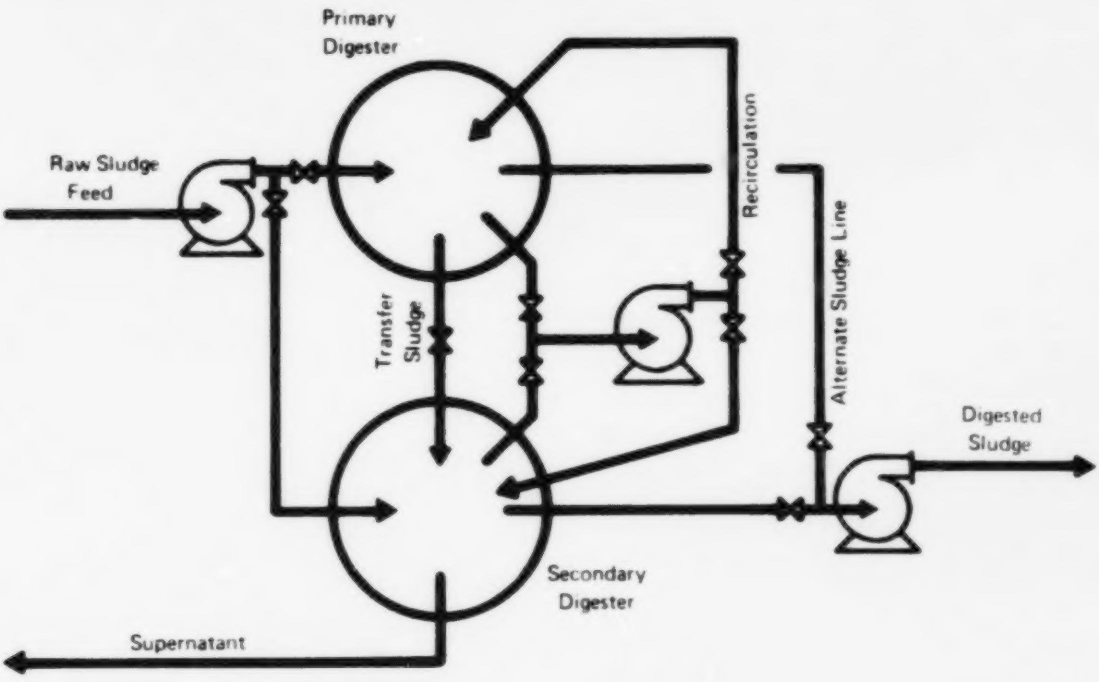


FIGURE 2-1
EXAMPLE OF A SIMPLE LINE DIAGRAM

This diagram is used to illustrate the various alternative routes that can be used for corrective action or in case of emergencies.

The second step is to fill in the information about your plant in Columns A and B of Part I. Your plant O & M manual should show this information.

The third step is to compare the existing operation with the design conditions. For example, the sample Part I sheet shows a design loading of 0.06 lbs. of VS per cu.ft. per day opposite the "Two Stage, Conventional" digester. Present operation shows 0.05 lbs. of VS per cu.ft. per day which is considered adequate since it is close to the design and therefore not overloaded.

The next several steps involve Part II where the procedure is repeated except that the information for Column C is taken from actual plant data on present operation. This information is then compared with the ranges given in the first column and significant differences noted as Not Adequate in Column D.

In this example, the total solids in the supernatant is the only real problem since it is twice as high as recommended. By referring to the Troubleshooting Guides, the operator can get some help on answers to solve the problem.

It is recommended that a plant review be conducted every six months for full control.

PLANT REVIEW CHECK LIST   PART I

INSTRUCTIONS

1. Column A – Mark number of units or X, whichever applies, in yes column for equipment on site
2. Column B – Use engineering data or O & M Manual and write in design information
3. Column C – Write in actual plant values
4. Column D – Make a comparison between Columns B and C and mark X in appropriate D column
5. Column E – Mark X in appropriate column
6. Column F – Comments

	A		B	C	D		E		F
	Yes	No	Design Size or Capacity	Comparison or Measurement	Adequate	Not Adequate	Is An Alternate Available Yes	No	Comments
[illegible]									
[illegible]									
[illegible]									
[illegible] 0.03 to 0.10 lbs. of VS cu ft /day			gallons lbs VS per cu ft /day	gallons lbs. VS per cu ft./day					
[illegible]									
[illegible] 0.03 to 0.10 lbs. of VS cu ft /day			gallons lbs. VS per cu ft. /day	gallons lbs VS per cu ft /day					
[illegible]									
[illegible]	✕		250,000 gallons 0.06 lbs VS per cu ft /day	250,000 gallons 0.05 lbs. VS per cu ft /day					Vegetable wastes causing overload
[illegible] 0.03 to 0.10 lbs. of VS cu ft /day									
[illegible]									
[illegible] 0.10 to 0.40 lbs. of VS cu ft /day									
[illegible]									
1. [illegible]									
2. [illegible]	✕								

SUPPORT SYSTEMS *Note number of equipment failures during past 12 months in Column C*									
A. Pumps									
1. Raw sludge feed	1		80 g.p.m	None	X		X		
2. Recirculation	1		120 g.p.m	Motor burned out once	X			X	Sludge thin in summer
3. Sludge withdrawal	1		80 g.p.m	One bearing failure	X		X		
B. Sludge Heating Equipment									
1. Submerged burners									
2. Steam injection									
3. Steam into preheat tank									
4. Internal hot water heat exchanger									
5. External hot water heat exchanger	X			None	X			X	
C. Sludge Mixers									
1. Internal fixed mixers	X		CRP gas mixer	None	X			X	Diffusers clog when gas production drops
2. Internal moving mixers									
3. Recirculation	X								
D. Covers									
1. Primary Tank									Dome tilts when gas production is high
None									
Fixed									
Floating									
Gasholder	X		3,000 cu ft	None	X				
2. Secondary Tank									
None									
Fixed									
Floating									
Gas Holder	X		3,000 cu ft	None	X				

PLANT REVIEW CHECK LIST PART II

INSTRUCTIONS

1. Column A — An X in the Yes column shows plant is doing something or answers a question
2. Column B — Indicate from engineering data appropriate information
3. Column C — Write in actual average data
4. Column D — Compare Column C with initial column data and mark an X in appropriate D column
5. Column E — Indicate whether plant has an alternate available
6. Column F — Comments

	A		B	C	D		E		F
	Yes	No	Design Size or Capacity	Comparison or Measurement	Adequate	Not Adequate	Is An Alternate Available Yes	No	Comments
[illegible]	X		Timer	2 Min to hr	X		X		
[illegible]			6%	6% Average	X				
[illegible]			4%	3% Average	X				
Supernatant [illegible]				10,000 mg/l		X	X		Improves in fall
[illegible]	X			During rainy season April - June				X	
[illegible]		X					X		
[illegible]	X							X	More organic in summer
[illegible]		X					X		None
[illegible]				None					

[illegible]									
Note Normal ranges and frequencies are noted									
A. Tests									
1. Volatile acids (digester supernatant) daily to weekly; normal range [illegible]	×			1 per week 240 mg/l	×				Rises to 600-800 during industrial season
2. Alkalinity (as calcium carbonate) daily to weekly; normal range is about [illegible] greater than volatile acids	×			1 per week 2,800 mg/l	×				
3. Volatile acids/alkalinity ratio [illegible]	×			0.08	×				
4. Temperature—daily	×								
a. Feed sludge (raw)				50-60 deg. F.					
b. Heated digester [illegible]				94 deg F Summer 90 deg F Winter	× ×				
5. pH—daily									
a. Feed sludge (raw)	×			6.2 average	×				Drops to 6.7 in summer
b. Digested sludge [illegible]				6.9 average	×				
6. [illegible]									
a. Digester [illegible]	×			29-32 %	×				
7. Gas production—daily	×			26,000 cu ft day	×				
a. Digester average [illegible] per pound of VS destroyed				9 cu ft /lb VS destroyed	×				
8. Volatile solids—weekly									
a. Feed sludge [illegible]	×			76% average	×				Rises to 82% in summer
b. Digested sludge [illegible]	×			52% average	×				
V. PERSONNEL									
A. Is the staff adequate in size?	×			Day shift	×				
B. Are they qualified?	×			Operator III	×				
C. Is there a training program?	×				×				
VI. TANK CONDITION									
A. Cover									
1. Leaking									
2. Unlevel									Primary dome tilts
B. Structure									
1. In good condition?									
a. Walls									Leak 3 ft. from top on North side Found last summer after shock load
b. Floor									
C. Contents									
1. Thick scum layer									
2. Thick grit layer									
3. Foaming									

DIGESTER EQUIPMENT OPERATION

Digester equipment operation involves establishing a routine that will prevent problems before they occur. It also includes discovering any that exist, enabling the operator to make repairs on a scheduled basis. To accomplish these goals, the operator most consider what is happening before, during and after sludge is pumped into the digester.

This section summarizes the major things an operator should do in the routine operation of the plant. Not all of the equipment listed will apply to every plant. However, after reviewing the material that is included, select those that apply to your individual plant.

Drawings of equipment and more descriptive material is found in Part IV. Troubleshooting information for the equipment and process is found in Part I.

The Equipment Operation Guides are set up as follows:

Units—This names the units that are associated with the digester starting with raw sludge and following the sludge flow to the digester bottom drawoff.

What the Operator Does—Brief description of what the duties are associated with this unit.

How it is Done—Brief description of how duties are performed.

Frequency—Suggested frequency of duties with preferred and minimum frequency shown by slash mark.

References—Location of other information on the subject mainly in this manual.

EQUIPMENT OPERATION GUIDE 1 PRETREATMENT

UNIT	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
[illegible]	1. [illegible] 2. [illegible]	1. [illegible] 2. Visually check raw sludge samples.	[illegible] [illegible]	
[illegible]	1. [illegible] 2. [illegible]	1. [illegible] 2. [illegible]	[illegible] [illegible]	2-29
Bar Screen	1. [illegible]	1. [illegible]	[illegible]	

EQUIPMENT OPERATION GUIDE 2 RAW SLUDGE PUMPS

UNIT	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
Raw Sludge Pumps	1. [illegible]	1a. [illegible] b. [illegible]	[illegible] [illegible]	[illegible]
	2. [illegible]	2a. [illegible] b. [illegible]	[illegible] [illegible]	[illegible]
	3. [illegible]	3. [illegible] *Hydraulic overload is caused most frequently by leaving the wrong valve open or a pump on accidently.*	[illegible]	[illegible]
	4. Monitor sludge accumulation in clarifier	4a. Check the depth of sludge b. [illegible]	Daily [illegible]	

EQUIPMENT OPERATION GUIDE 3 DIGESTER COVERS

UNITS	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
Digester Covers–Fixed	1. Check roof for leaks.	1. Soap solution or audible sound of gas leaking. Check for odor.	Semiannually	TG 11
	2. Monitor pressure/vacuum relief valves.	2. Listen for gas escaping or air entering valve.	Weekly (temp. above freezing) 1-3 times daily in freezing weather	TG 11
	3. Test pressure/vacuum valves.	3. Match pressure relief point with design pressure by closing main gas valve under controlled conditions.	Semiannually	
Digester Covers–Floating	1. Check cover to see if level.	1. Visual or noting loss of gas.	Daily	TG 12
	2. Level an uneven cover.	2a. Distribute weights away from low spots.	As needed	TG 12
		b. Readjust cover rollers or guides.	Monthly	
		c. Pump water out of wells in condensation traps around edge of metal covers with traps.	Monthly	
	3. Test and monitor pressure vacuum relief valves.	3. (See fixed covers above.)	Semiannually	TG 10
	4. Control cover travel between maximum and minimum limits.	4. Stop pumping or transferring when cover reaches either limit. ***Failure to do this may result in the cover coming off at high level or collapsing if the vacuum relief fails at a low level.***	Daily	TG 12
Digester Covers–Gas Holder	1. Monitor rate of gas usage and dome travel limits.	1. Determine maximum and minimum travel limits for dome. Adjust gas usage to prevent dome reaching either limit.	Hourly/daily	TG 13
	2. Verify that guides and/or rollers are not binding.	2. Observe gas pressure while dome is moving. Gas pressure should stay constant and neither pressure or vacuum relief should open during travel.	Daily/monthly	TG 13

EQUIPMENT OPERATION GUIDE 4 MIXERS

UNITS	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
• External Mixers (Mechanically Driven From Outside)	1 Monitor motor amperage	1 Use ammeter at motor control center. Record readings. Decreasing readings could indicate excessive wear on rotating parts	Monthly	TG 8
	2 Monitor mixing action	2a Note visually the movement of sludge through sight glass in cover	Daily	
		b Measure depth of scum through thief hole. Increasing amounts might indicate need for further inspection	Quarterly	
Internal Mixers (Gas Type)	1 Monitor gas feed rates and distribution to feed points	1a Observe pressure at compressor and compare with manufacturer's or O&M manual information	Daily	TG [illegible]
		b Verify that gas is flowing to correct feed point by checking position of valves, observing manometer readings and/or feeling of gas line. Line with flowing gas will be warmer than those with no flow	Daily	
	2 Monitor mixing action	2 (See above on External Mixers.)		

EQUIPMENT OPERATION GUIDE 5 INTERNAL HEATERS

UNITS	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
Hot Water	1. Monitor temperature of sludge in recirculation line.	1a. Use temperature read-out gauges or thermometer. b. Take sample from recirculation pump and check with lab thermometer immediately after withdrawal.	Daily	TO 5
	2. Monitor water system for leaks and temperature.	2. Read water meters and compare inlet and outlet quantities of water to tell if there are leaks in water lines inside the digester.	Daily	TO 5
	3. Monitor water temperature.	3. Read thermometer. **Water temperature above 130 deg. F. (54 deg. C.) will cause sludge to bake on tube and cut down heat transfer.**		
Steam	1. Boiler pressures and temperature.	1. Gauges and thermometers hold within manufacturer's instruction limits.	Hourly	Manufacturer's literature
	2. Correct settings on feed valves.	2. The operator must know that correct valves are open ***before*** putting pressure on the line.		
	3. Condition of check valves.	3. Service on regular basis and replace worn valves. A good precaution is to install two valves in series to protect the boiler from sludge backing up into boiler tubes.	Quarterly	
	4. Monitor sludge temperature.	4. Use temperature readouts or gauges. **Water temperature above 130 deg. F. (54 deg. C.) will cause sludge to bake on tube and cut down heat transfer.**	Daily	

EQUIPMENT OPERATION GUIDE 6 EXTERNAL HEATERS

UNITS	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]

EQUIPMENT OPERATION GUIDE 7 RECIRCULATION PUMPS

UNITS	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
Centrifugal	1. Check pump output	1a. Check pressure gauge. If lower than normal reading, isolate pump. Lock out and inspect for plugged impeller. b. Record ammeter readings and watch trend in readings. Lower amperage indicates wear on the impeller.	Hourly/daily Weekly/monthly	TG 4 TG 4
Positive Displacement Piston Type	1. Check pump output	1. Check pressure gauge. If needle is not deflecting normal amount, ball check may have obstructions. Lock out, isolate and inspect ball chamber. NOTE: Relieve pressure ***before*** opening chamber; open valves ***before*** turning pump on.	Hourly/daily	TG 4

EQUIPMENT OPERATION GUIDE 8 SUPERNATANT SYSTEM

UNITS	WHAT OPERATOR DOES	HOW IT IS DONE	FREQUENCY	REFERENCES
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

DIGESTER PROCESS CONTROL

INTRODUCTION

The first thought that comes to most operator's minds when the subject of control is mentioned is laboratory testing. However, there are a variety of "tools" that should not be overlooked in addition to what the lab results can provide. These include:

1. Eyes (to judge sludge thickness, supernatant quality, desirable color of digested sludge, etc.)

2. Ears (changes in thickness of raw sludge can be detected by listening to a piston pump "hammer" when sludge gets too thin)

3. Nose (some industrial wastes, such as phenolic, that can cause digester problems can be "smelled" in time to prepare for handling them)

4. Hands (feeling texture of sludge can tip the experienced operator to sand, grease or uncomminuted components)

Nonstandard tests are also used. These are described on page 2-29.

A common question that the operator may ask is: "What is normal for my digester?" This has to be considered for the individual plant. Some insight may be gained by answering the following questions:

1. Is the digester operation taking more hours than it should? (See the section on Manpower Requirements, Part III.)

2. Is the digester causing problems in other parts of the plant?
   a. Supernatant in the primary clarifier?
   b. Supernatant in the aerators?
   c. Foaming over the digester walls?
   d. Excess BOD, SS or turbidity in the effluent?

3. Is the digester causing problems off-site?
   a. Odors from the digester?
   b. Odors from the sludge beds?

4. Is the system costing too much money to maintain?
   a. Some estimate the average annual maintenance cost at 4% of capital cost.
   b. Others use 2% of capital cost for the first 10 years of use and 5% after this time, as an estimate.
   c. EPA cost estimates show that digester operation costs are about 10% of the annual plant operation and maintenance costs and drying bed operation runs about 5% of plant costs.

5. Is the system being upset by industrial wastes?

6. Are operating procedures letting the digester become upset?

Some of these problems can be resolved by looking at the way certain operations are done and revising them to prevent possible problems and improve digestion results.

A number of operation procedures are reviewed in the following pages. An operation check list is included at the close of the section.

HOW TO SET UP A FEED SCHEDULE

First, the difference between feeding and loading should be explained. Feeding concerns only the raw sludge system while loading considers both the feed and the volume and contents of the digester.

Keeping excess water at a minimum and feeding at regular intervals are important features of a feeding schedule.

Control of Excess Water

Controlling the solids concentration going to the digester may be done in several ways as described in Operation Guide 1.

Total solids is the normal method for determining solids concentration. This test is described on page 4-20 and Appendix E-9.

Three other methods can be substituted for the total solids test by correlating them with the total solids test results. These are: lab centrifuge testing, motor amperage and the Imhoff cone test. An example of how this is done is given below, using the lab centrifuge to correlate results.

Example: Take six samples ranging from thin to thick sludge, approximately 1% to 8% total solids. Run both tests on each concentration and plot results. Run centrifuge at maximum speed for 15 minutes. Be sure test is run at same speed for same time period each time.

1. Record total solids and value of the other indicator at 5 or 6 points between 1% and 8% total solids.
2. Plot on a graph, drawing a line connecting the points as shown on Figure 2-2.
3. Determine the lowest desired solids feed level and set up system to stop pumping when below that percent solids.

Feed Schedule Interval

Although the frequency of pumping may vary from once a day to continuous, operators should review the schedule to see if it can be improved. The best feed schedule is continuous at a low rate. The next best is frequent pumping for short periods and once a day is the worst. Several methods are discussed in Operation Guide 1.

A caution about pumping to the digester: *do not allow the pump to be left on accidentally.* Hydraulic washout is one of the major causes of digester upset and all too often it is traced back to an operator who left a raw sludge pump control in the "on" or "hand" position overnight.

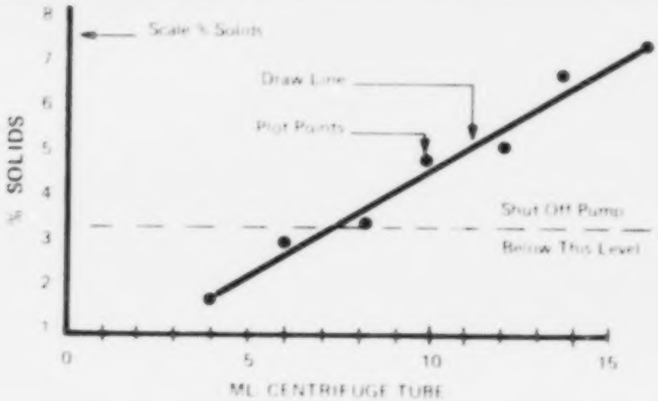


FIGURE 2-2
CORRELATION GRAPH

OPERATION GUIDE 1 DIGESTER FEEDING

DESIRED GOAL	PLANT EQUIPMENT/ CONDITIONS	METHOD
A. Don't pump excess water to the digester.	1. Sludge drawn to pit or vault before pumping to the digester.	1a. Watch sludge while being drawn. Shut off when too thin. b. Sample and compare different sludge concentrations by running lab centrifuge tests or use Imhoff cone for quick estimate.
	2. Sludge drawn directly from clarifier hopper or gravity thickener with positive displacement pump.	2a. Check pump discharge gauge, higher pressure generally indicates thicker sludge. b. Compare sound of pump with sludge thickness. Excessive hammering of piston pump indicates thin sludge. c. Coordinate total solids with pump amperage. Tie ammeter to pump controls to shut it off if sludge is too thin. See page 3-34, Gadgets. d. Install solids concentration meter that reads percent solids and use signal from meter coordinated with time clock to control feed solids concentration.
B. Pump at regular intervals to prevent adding food too fast for bacterial action and prevent temperature change.	1. Single stage digesters.	1a. Pump at least several times per day by hand and stop when solids drop too low. b. Install time clock control if none provided and set schedule for 10 a.m.–midnight. Let settle overnight with no mixing and draw supernatant in early morning.
	2. Two stage digesters.	2a. Spread pumping over 24 hours *unless freezing weather makes this unsafe when plant is not manned.* Control pumping so that excessive water is not pumped during low flow periods. See Methods 2c and 2d in A above.
C. Review pumping schedules and respond to changing conditions.	1. Winter vs. summer.	1a. Cold weather operation causes problems with sludge bridging over in rectangular clarifiers. Closer control must be exercised to avoid reducing digester temperatures. b. Increase pumping time during storms because of increase in solids. Decrease afterwards because solids accumulate in sewer lines and do not reach the plant.
	2. Industrial wastes.	2a. Most vegetable processing wastes increase the volume of sludge and decrease solids content. Adjust pumping rates to match changing conditions.

HOW TO CONTROL LOADING

In order to calculate loading, the operator must have a record of the pounds of volatile solids per day being fed to the digester and must also know the volume of usable capacity in tank. This calculation is given in Part IV, The Basics, on page 4-20.

As noted in the introduction to this section, two of the three major causes of digester upset are hydraulic and organic overload. In the first case excessive amounts of water flush out the methane formers, leaving the tougher acid formers to increase and cause volatile acids to use up the buffering capacity.

In the case of organic overload, either the amount of volatile solids increases due to an excess of food *or* the digester capacity is reduced by scum and grit accumulations, making the effective volume too small for the amount of food being handled.

One approach to making a loading survey is presented below.

Organic Loading Survey

To get a representative idea of an average loading, take a series of grab samples on the raw sludge feed three or four times throughout the day and on several days of the week.

Use the procedure given on page 2-21 and the calculations presented on page 4-21 and calculate the actual available volume of digester space and the volatile solids expressed in pounds per day. Do the calculations and compare the figures with those listed on page 2-4. If the numbers are significantly more than those listed in the manual as being average or normal, it's time to remove the grit and sand from the bottom of the digester and restore the original available volume.

Some general guidelines that apply to loading control are noted here and should be included when the procedures for digester loading control are written for individual plants.

General Loading Guidelines

Operators generally have no control over the characteristics or the total pounds of solids to be fed to the digester. They do, however, have control over the concentration and frequency of feeding. These are two very important controls, and they are also the ones which cause the greatest number of sludge-handling problems.

The operator must maintain the best possible balance between the incoming raw sludge and the sludge already in the digester. This is best done by:

1. Establishing a feed schedule which is frequent and in small amounts. A time clock control on the pump will allow this. However, the schedule should be set so that excess water is not pumped at night.

2. Feeding the highest solids concentration possible. Typical total solids ranges for various sludges are:

primary raw sludge	5-8%
waste-activated	1½-2%
trickling filter humus	1-3%
mixed primary/waste activated	3-5%

3. Obtaining good mixing throughout the tank. A general rule of thumb is to recycle a quantity equal to the volume of the tank once a day. If the primary digester has a volume of 250,000 gallons (950000 l) the mixer should be capable of moving at least 175 gpm (11 l/sec.).

4. Not overfeeding. One rule of thumb says that the volatile solids in the total daily feed should not exceed 5% of the volatile solids already in the digester.

5. Controlling digested sludge withdrawal to keep buffering capacity high.

6. Maintaining an efficient grit removal system.

Methods for Determining Digester Capacity

1. Measure the amount of grit and inorganic material in the bottom of the digester by probing with a long stick or piece of pipe and estimate the total cubic feet occupied by this material. Another method of finding the top of the grit layer is to take temperature readings at lower digester depths. The grit layer will be several degrees cooler.
2. If scum blankets have formed at the surface of the tank, they should be measured. One method of measuring this is to use a stick with a hinged flap of metal. When the stick is passed down through the scum layer and then lifted up, the flap will open up underneath the scum blanket. This device is discussed more fully on page 3-31.

OPERATION GUIDE 2 DIGESTER LOADING

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Prevent hydraulic overload.	1. Single stage digester, manual sludge pumping.	1a. Pump thickest sludge possible, taking care not to leave pump on accidently.
	2. All types digesters, automatic pumping.	2a. Control pump schedule so that pumping rate equals sludge accumulation rate. b. Impress personnel with the importance of not over-pumping or leaving pump on accidently.
B. Prevent organic overload.	1. Single stage digesters.	1a. Spread feeding over maximum portion of the day. b. Clean digester on regular schedule (every 2-3 years). See Part III on Digester Cleaning. c. Control industrial loading by ordinance adoption and enforcement. d. Monitor volatile solids loading and VA/Alk ratio and be prepared to take corrective action if necessary to restore buffering. e. Graph digester lab test data and watch for trends.
	2. Multiple tanks.	2a. Consider the information in B–1a-1e above. b. Spread loading between several tanks if one tends toward upset. c. Recycle from the bottom of a secondary digester or another well buffered primary digester at a rate of 50% of raw feed per day. d. Adjust temperature—find most efficient level for particular waste. e. Increase mixing to maximum capacity.

HOW TO CONTROL DIGESTER TEMPERATURE

Specific temperature control methods will depend on equipment used for heating the digester. Because it is important to hold constant temperatures, the operator should be sure of the following:

1. The temperature should be measured at a point that represents the active part of the digester.

2. The heating system should control the temperature evenly so that it is not causing digester upset.

3. If cold weather makes temperature control erratic (changes of more than 2°F per day), lower the operating temperature to a level that can be kept more constant.

Some operation suggestions are given on Operation Guide 3 and problems with temperature control are discussed in Troubleshooting Guides 5 and 6. Heating equipment operation is discussed in Equipment Operation Guides 5 and 6.

HOW TO CONTROL MIXING

The goals of mixing control are to bring bacteria in contact with the food as it is added and to keep scum and grit formations at a minimum. Internal, external and recirculation methods are discussed in Part IV, The Basics. Troubleshooting Guides 7, 8 and 9 give more information on the subject.

OPERATION GUIDE 3 DIGESTER TEMPERATURE CONTROL

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Get accurate readings.	1. No temperature gauges or installed thermometer.	1a. Allow recirculation pump to run for at least 10 minutes, pulling from "active zone." Pull sample and let bucket come to sludge temperature, dump first sample, draw another and measure temperature using lab thermometer. b. Lower sampler into digester, pick samples at various levels according to procedure in 1a and measure with lab thermometer. (See page 3-29, Gadgets.)
	2. Installed measuring device giving questionable readings.	2a. Use either method 1a or 1b above to check temperature device, taking sample as close as possible to where the device measures temperature. b. If device is in a recirculation pump line, be sure pump is operating and pulling representative sample.
B. Change operating temperature up or down by at least 5 deg. F. (2.8 deg. C.)	1. Changing weather condition or waste characteristics.	1a. Adjust heat controls such that temperature does not change more than 1 deg. F. (0.5 deg. C.) per day.
C. Desire to try thermophylic range.	1. Heating equipment capable of maintaining 130 deg. F. (54 deg. C.), multiple tanks available.	1a. Consult references in Appendix B. b. Use only one tank at a time. c. Change temperature at a rate of 1 deg. F. (0.5 deg. C.) per day or 3 deg. F. (1.7 deg. C.) in two days at maximum. d. Be prepared for a month period of transition. e. Control using VA/Alk ratio and hold below 0.1.

The mixing schedule will vary depending on the type of equipment and tank configuration. The important things to consider are:

1. Does the mixing system do a good job of bringing food in contact with the bacteria?
2. Are scum blankets and grit accumulations reducing the volume of the tank enough to cause organic overload?
3. Is the mixing (particularly gas type) causing supernatant quality to upset the plant?

Scum Blanket Control

Adequate mixing normally prevents scum from forming a blanket. However, many digesters were installed with no mixers or inadequate mixing devices. Under these conditions, the scum blanket is a major problem.

Keeping the scum blanket moist will normally prevent the problem. This allows gas to pass through and assist in preventing the blanket from becoming too thick. A maximum depth should be less than 24 inches.

Scum blankets in digesters usually have a rolling movement if mechanical or natural digester gas mixing is adequate. This movement can be observed through the the thief hole. If movement is slight or not present, the operator should check mixer operation or probe the scum blanket for thickness.

Several suggestions on mixing control are given in Operation Guide 4.

OPERATION GUIDE 4 HOW TO CONTROL MIXING

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Keep scum and grit accumulation at a minimum and provide good contact between food and bacteria.	1. Single stage digester.	1a. Run mixing equipment following each sludge addition but shut off when it affects supernatant quality. Time clock control on both sludge pump and mixer helps accomplish this. b. If mixer fails, check possibility of using raw sludge pump to provide some mixing when not pumping raw sludge. c. Draw level down to minimum and recirculate and mix simultaneously for 24-48 hours every six months if buildups are a problem.
	2. Two stage digesters.	2a. Run mixer continuously in primary digester unless secondary supernatant quality goes above 5,000 mg/l total solids. If above 5,000 mg/l, decrease mixing time by manual or time clock control. Measure scum and grit accumulation to find optimum mixing time.
B. Break up scum blanket	1. Mixing equipment not operable, several digesters available.	1a. Adjust number of tanks to allow loading ratio of 0.3-0.4 lb. VS/cu.ft./day (4.8-6.4 kg/m^3/day). Gas generation in the tank will cause natural mixing. *Caution:* The loading rate must be held in this range continuously and the VA/Alk ratio monitored to keep the tank in control. b. Introduce compressed digester gas into the bottom sludge draw-off line and allow bubbles to provide limited mixing.

HOW TO CONTROL SUPERNATANT QUALITY AND EFFECTS

One of the traps that some operators fall into is believing that all process problems in other parts of the plant are caused by outside sources, when many times the trouble is from digester supernatant returning to the headworks or other points in the plant. Each plant will have its own limits. However, problems begin to develop in most plants if the supernatant total solids exceed 0.5 to 0.75% (5000 to 7500 mg/l).

General Guidelines for Supernatant Control

When drawing off supernatant in unmixed digesters, the operator should select a drawoff point which will give the best supernatant. In single tanks with internal mixers, the operator should stop mixing for periods of 6-12 hours or plan for intermittent mixing to allow settling before selecting and drawing off supernatant. This will also require programming sludge feed and sludge withdrawal.

Effects of Tank Types on Supernatant Quality. Where two tank systems are operating, the active sludge mixture is transferred from the primary digester to the secondary where the sludge is detained without mixing. The supernatant qualities obtained from the secondary digester will depend on the detention time and the type of sludge feed.

Single stage tanks with moderate loading will generally produce good supernatant if the operator can find the right layer. Part of the key to success is having several drawoff points and selecting the best one. Several patented supernatant selectors are installed in digesters but even the best ones are subject to plugging with hair, rags and other stringy debris. The superior "selector" is the vigilant operator who is willing to experiment until he finds the optimum pattern for mixing, resting and drawing the sought after "clear" supernatant.

The type of plant also affects supernatant quality as shown by Table II-1 below.

Table II-1
TABLE OF EXPECTED RANGES OF SUPERNATANT QUALITY FOR DIFFERENT TYPE PLANTS

	Primary Plants (mg/l)	**Trickling Filters* (mg/l)**	**Activated Sludge Plants* (mg/l)**
Suspended solids	200-1,000	500-5,000	5,000-15,000
BOD_5	500-3,000	500-5,000	1,000-10,000
COD	1,000-5,000	2,000-10,000	3,000-30,000
Ammonia as NH_3	300-400	400-600	500-1,000
Total phosphorus as P	50-200	100-300	300-1,000

* *Includes primary sludge*

Some of the best results are obtained by drawing the supernatant into an open lagoon or drying bed and skimming the layer that forms with wide circular decant pans. Greater efficiency results when the surface area to depth ratio is large. If land is available and problems exist, this solution should be considered.

High rate gas mixing tends to homogenize the sludge and contribute to poor quality supernatant. One operator had success in improving supernatant quality by adding about 3 mg/l of water soluble anionic polymer to the gravity thickener and reducing the total operating hours of the gas mixer. This reduced the detention time in the digester because thicker sludge was pumped and the reduced mixing time produced lower solids in the supernatant. The product was Zimmite ZT-650.

Other considerations are summarized in Operation Guide 5. Also see Troubleshooting Guide 2.

OPERATION GUIDE 5 SUPERNATANT CONTROL

DESIRED GOAL	PLANT EQUIPMENT/ CONDITION	METHOD
A. Liquid quality that will not affect the rest of the plant.	1. Single tank fixed cover.	1a. Feed digester at as slow a rate as possible, do all mixing after supernatant has quit displacing and allow tank to set without mixing 8-12 hours before feeding again. b. Make up jars containing samples of supernatant stabilized with formaldehyde, which can be used as a standard by operators showing what is and is not acceptable quality.
	2. Single digester, floating cover, single draw-off.	2a. Adjust tank level until best quality liquid is found and operate within these limits. b. Install swivel joint and 4-6 foot length of pipe to draw-off line to allow selection over wider range. See page 3-35, Gadgets.
B. Prevent problems of overload to gravity thickener.	1. Poor quality supernatant due to overloaded digester.	1a. Add polymer to sludge going to thickener to increase solids, decrease quantity of supernatant and increase digester detention time.
C. Prevent high demand supernatant going to aerators. Sidestream treatment.	1. Poor quality due to overloaded digester.	1a. If extra aerator is available, preaerate before discharging to aerator. b. Aerobically digest supernatant to reduce demand. Air demand will be high for first few days but will taper off to 20-25 cfm/cu.ft. (20-25 m^3/min./m^3) tank capacity.
D. Eliminate all recycle to process.	1. Poor quality supernatant due to overload or poor separation in digester.	1a. Discharge to available drying bed or lagoon and spray irrigate decantate. b. Haul or process digested sludge at a rate that will prevent supernatant return. c. Sell to firms or individuals requiring liquids for composting processes.

HOW TO CONTROL SLUDGE WITHDRAWAL

When sludge is drawn out of the digester, either to beds or other sludge handling facilities, there are several important considerations.

1. In small plants, particularly with single-stage digesters, at least 12 hours should lapse between pumping raw sludge and sludge withdrawal. Additionally, the contents should be well mixed to prevent pulling out raw sludge that could create odors as well as contain pathogens.

2. Care must be taken to prevent pulling air into fixed cover digesters when sludge is withdrawn. Sludge from multiple tank systems can be drawn at a rate that will allow gas from another tank to be pulled back into the emptying tank. Single tank operators should pull sludge out slowly enough that air is not pulled in or kept at a minimum. Explosive conditions exist when the methane concentration is below 20% on a volume basis.

HOW TO USE LAB TESTS AND OTHER INFORMATION FOR PROCESS CONTROL

Just as the driver of a car does several things at once to keep control of the car, the operator looks at several indicators to keep the digester from "upsetting." And, like the driver who uses the steering action to keep the car on the road, the operator can use lab tests, such as the volatile acids and alkalinity, for process control. Other tests are also needed to give the full picture and these will be discussed in the following pages.

Methods for running lab tests are found in Appendix E, and a discussion of what the various parameters show is covered in Part IV, The Basics, starting on page 4-11.

Important Indicators

There are certain indicators which measure the progress of sludge digestion and warn about impending upset. No one variable can be used alone to predict problems, several must be considered together. Control indicators in order of importance are:

1. Volatile acids to alkalinity ratio.
2. Gas production rates, both CH_4 and CO_2
3. pH
4. Volatile solids reduction (digester efficiency)

None of the above used singly can indicate the condition of the digestion process. For example, volatile acid readings may increase, but which does it indicate:

1. A decrease in percent methane (a rise in percent CO_2)?
2. A decrease in alkalinity?
3. No change in percent methane production?
4. A decrease in pH?
5. A problem or no problem?

Large increases in volatile acids may take place before pH is changed if the digester is heavily buffered (has high alkalinity). Changes in volatile acids mean more when considered with alkalinity.

Obviously, the operator needs more information before responding to the indicator.

The operator is cautioned against looking at an absolute number. The rate of change is much more significant. In summary, then, trends of these indicators are the most useful to predict the progress of digestion and as signals of process upset. A discussion of trends is in Part IV, The Basics, page 4-16, and Appendix, G-2.

Importance of Samples in Process Control

Sampling is the first step in waste analysis. It is absolutely necessary to take good samples to get reliable usable tests. Good samples are obtained by following a few simple rules:

1. The sample must be representative. For example, when drawing samples from an on-off pumping operation, allow pump to run for several minutes to clear the line; then make a composite sample during the time the pump is running. This is done by drawing three samples, at the beginning, at mid-point and at the end of pumping period. Equal volumes of sample should be mixed together.

2. Always run pH and temperature tests immediately (5-10 minutes) to avoid deterioration. If samples are allowed to set too long, CO_2 will be released, causing the pH to rise. Always use the same length of time from collection to determination for each test run. It is important to standardize when taking temperatures. Don't use a warm bucket or thermometer one day and a cold one the next day.

3. Always refrigerate the sample if tests are not run immediately. When storing a raw sludge sample in a refrigerator, it's a good idea to use a plastic wrap over the top of the jar with a rubber band on it to hold it in place. This will allow any gases that might collect in the sample to expand without bursting the jar.

4. The container should be cleaned thoroughly before and after use.

Sample Points for Control Information

There is no specific set or list of tests than can fit all digester systems due to the variability and complexity of systems. However, in general, the following points are usually sampled for digester monitoring and control.

1. Raw sludge
2. Digester sludge (active zone)
3. Digested sludge
4. Supernatant
5. Digester gas

Raw Sludge. Tests performed on samples of raw sludge tell an operator what type of food is being fed to a digester. The operator is actually feeding a tank full of hungry organisms their daily rations, much as a zookeeper would distribute food to cages full of animals. By knowing the condition (pH and temperature) and the content (total and volatile solids), the operator can predict to some degree how the digester will react.

This sample is normally taken at the raw sludge pump or from a well-mixed portion of a sludge pit or vault.

Digester Sludge. The second major sample should be taken from a point in the digester that represents the well-mixed active portion of the primary digester. This determines what is happening inside the tank. This sample gives the operator information on the alkalinity and volatile acids as well as on the solids that will be used in other calculations (described on page 4-20).

Samples may be taken from sample lines, from overflow boxes where sludge passes from a primary to a secondary digester or from a recirculation pump or line where a corporation cock is installed.

Digested Sludge. The contents of the bottom sludge in the digester is another important point which gives the operator information on how the process is proceeding. This sample may represent what is being transferred from the bottom of a primary digester to a secondary digester, or it may represent the bottom sludge being withdrawn for disposal.

Quantities of sludge transferred from one digester to another or from a digester to a drying bed can usually be determined by:

1. Calculating the volume added to a drying bed, sludge truck or dewatering unit and recording it as gallons per day or gallons per month.

2. Calculating the diameter of a circular digester, the number of gallons per inch or per foot which measure the change in liquid depth, and calculating and recording the volume.

Supernatant. Grab samples of supernatant, if they are fairly uniform and continuous, will give a good idea of what is happening. However, some method must be used to decide when to begin and stop transferring supernatant back to the process. Many times this is done by visual observation. Some operators use an Imhoff cone with a cutoff point of 50 milliliters per liter after 30 minutes of settling to tell them when to stop the flow of supernatant and let the digester rest.

Carbon Dioxide. This is a most easily measured component of the digester gas. Because the sum of the CO_2 and CH_4 is approximately 100%, the amount of CH_4 can be roughly estimated by measuring the CO_2. Well operating tanks range between 25-35% CO_2. The percent of CO_2 can be an early indicator of approaching problems if the trend is upward.

The percent CO_2 will increase shortly after feeding, if sludge is fed two or three times per day. Information should be obtained during different times of the day to find normal values for the plant.

Several CO_2 analyzers are on the market, such as those manufactured by Hays or Orsat. The CO_2 content of the gas coupled with the quantity of gas produced shows the immediate response to how the food is being utilized. If the CO_2 content stays consistently high, it can be a trend toward excess acid production and trouble.

Samples may be taken several places. If gas is piped into the lab and used for Bunsen burners, this can be a very adequate sampling point. It is important to purge the line before collecting a sample. This is done by lighting the burner and letting it burn for a minute or so, turning it off to collect the sample. If samples cannot be run in the lab, the sampling device can be located at a sample point on the digester gas line.

Suggested Tests and Frequency. The following table lists the possible tests and suggested frequencies for a plant with approximately 1 to 2 mgd and two or more digesters.

This table is a suggestion only and would have to be adapted to the type of sludge being received at a plant, the severity of overloading and a number of other factors, but gives some idea of how often information could and should be obtained. Two columns are shown, the first showing the optimum, the second showing the minimum test frequencies.

TABLE II-2
SUGGESTED SAMPLE TESTS AND FREQUENCY
1-2 MGD PLANT, TWO DIGESTERS

	TEMP.		TS		VS		CO_2	pH		ALK		VA		QUANTITY	
Raw Sludge	D	(D)	D	(4/W)	D	(4/W		D	(W)					D	(D)
Recirculation Sludge	D	(D)	D	(4/W)	D	(4/W		D	(D)	D	(W)	D	(W)		
Bottom Primary	D	(W)	W	(M)	W	(M)		D	(W)	2W	(W)	2W	(W)	D^a	(D^a)
Bottom Secondary	M/2	(M)	W	(M)	W	(M)		W	(M)					D^b	(D^b)
Supernatant	W	(M)	W	(W)	W	(W)		D	(W)					D	(D)
Gas							D							W	(Y/4)
Scum			Y/4	(Y/2)	Y/4	(Y/2								M	(Y/4)
Grit			Y/4	(Y/2)	Y/4	(Y/2								M	(Y/4)
Depth Series	Y/4	(Y/2)	Y/4	(Y/2)	Y/4	(Y/2)		Y/4	(Y/2)	Y/4	(Y/2)	Y/4	(Y/2)		

( ) = Minimum frequency
C = Continuous
D = Daily
W = Weekly
M = Monthly

Y = Yearly
M/2 = Twice a month
Y/2 = Twice a year
4/W = Four times a week
a = Amount transferred to secondary, if applicable
b = Or as often as drawn to disposal point

Non-Standard Tests

There are some non-standard tests which are not given in the books which will provide additional useful information.

Visual Gas Test. A yellow flame with blue at the base is normal at the waste gas burner. When too much blue is present and the flame will not stay lit, this may indicate too much CO_2. An orange flame with smoke may be present when the digester has a high sulfur contact.

Test for Grit. Estimates on the amount of grit in the sludge may be obtained by allowing tap water to run into an open beaker of sludge at a slow rate to wash most of the light solids out, leaving the grit in the bottom of the beaker. If the amount of water run into the beaker is the same each time, then the operator can get some visual feeling for the amount of grit in raw sludge, the sludge being drawn out, and the amount in the recirculated sludge. It is difficult to assign numbers to these amounts, but visually the operator can tell if the amount is increasing or decreasing. Using this information along with actual sounding of the digester can give him a feel for the probable grit build-up in the digester.

Sniff Test. Another bit of information can be gained by the non-standard "sniff" test. Simply smelling the sludge samples can tell the operator whether it's septic, sour, well-digested or, in the case of raw sludge samples, whether there are chemicals such as oils, solvents, or other types of materials that might be harmful to the digester. Experience is the best teacher for drawing conclusions from this type of a test, but it should not be ignored by the operator. Examples of digester supernatant sniff indicators are rotten egg odors which may indicate organic overload and a rancid butter smell which may be present when heavy metals toxicity exists.

Digester Profiles

In addition to the above tests, samples should be taken inside the digester. This can be done by lowering sample collectors into the tank at least twice yearly. One procedure is to set aside half a day, or a day if necessary, to take samples at five-foot intervals from top to bottom of all digesters and set up total solids, volatile solids, pH, temperature, and alkalinity on the entire series. By plotting the results after they are obtained, it is possible to have a pretty good idea of how much grit is on the tank bottom, whether there are pockets of undigested material, or whether the temperature is not uniform all the way through. These samples can be taken, using a homemade sampling device, one of which is described on page 3-29. The important thing is to collect a sample that represents the particular level that the sample is taken from.

It is also a good idea to take samples from several different locations and depths. Samples can be taken from prepared sampling holes known as "thief holes." If the tank has a floating cover, it is possible to lower a sampling device alongside the floating cover into the tank. It will probably be necessary to break away the scum layer, and although this is not the best location, it will give some information if no other sampling points are available. As a last resort a manhole cover can be taken off; however, safety precautions should be strictly observed. A floating cover should be down on the corbels before the manhole cover is removed.

At the same time the digester profile is being done, both the amount of scum and the amount of grit should be recorded. In order to find the amount of grit that has accumulated, several points in the digester should be sounded using a long stick or a piece of pipe to determine where the top of the grit layer is. Then force the stick down through it until the floor is reached and record the difference in the two measurements. If the plans on the digester are available, the grit layer can be estimated by using the top of the wall as a reference point and measuring down to the top of the grit layer, noting the difference between these measurements.

OPERATIONS CHECK LIST

The following list is prepared to help you make up your own check list and may include items not within your process. Use only those which apply to your plant.

	Suggested Frequency
A. Feed Sludge	
1. Record volume pumped for a 24-hour period.	Daily
2. Run total solids test and compare with amount pumped in to be sure too much water is not being fed.	Weekly (1-3 times)
3. Check pump operation for packing gland leaks, proper adjustment of cooling water, unusual noises, undue bearing heat, and suction and discharge pressures.	Daily
4. Monitor pump time clock operation for proper control and check running time with sludge consistency.	Daily
B. Recirculated Sludge	
1. Record temperature of recirculated sludge.	Daily
2. Collect sample of recirculated sludge and run tests.	Weekly (1-3 times)
3. Check boiler temperatures, burner flame, and exhaust fan for proper operation.	Daily
4. Check hot water circulating temperatures.	Daily
5. Check and record heat exchanger inlet and outlet temperatures.	Daily
6. Check for leaks in sludge lines.	Weekly
7. Check pump operation — packing gland leaks, proper adjustment of cooling water, unusual noises, undue bearing temperatures and suction and discharge pressures.	Daily
C. Digesters	
1. Gas manometers for proper digester gas pressure.	Daily
2. Drain condensate traps — more often if needed.	4/daily
3. Drain sediment traps.	Daily
4. Waste gas burner for proper flame.	Daily
5. Record gas pressures.	Daily
6. Record floating cover position, check cover guides and check for gas leaks.	Daily
7. Record digester and natural gas meter readings.	Daily
8. Check and record fuel oil.	Daily
9. On gas mixers check flow of gas to each feed point.	Daily
10. Check internal moving mixers for proper operation.	Daily
11. Pressure relief and vacuum breaker valves — Verify operation with manometer and check for leaking gas.	Daily/Weekly
12. Check supernatant tubes for proper operation, collect sample, and hose down supernatant box.	Daily
13. Check level and condition of water seal on digester cover.	Daily
14. Check flow meters for correct flows, leaks and vibration.	Daily
15. Check feed sludge density meter for correct density, leaks and vibration.	Daily
16. Check scum blanket through sight glass.	Daily
17. Check gas storage tank for gas leaks and odor. Record readings on pressure gauges and drain condensate traps.	Daily

	Suggested Frequency
18. Check all gas line piping for leaks. Test with soapy solution if a leak is suspected.	Weekly
19. Check gas pressure regulators and verify with manometer reading.	Monthly
20. Check flame trap arrestors by noting the pressure drop across unit or that equipment downstream is working.	Monthly
21. Check scum blanket for dryness and depth.	Monthly
22. Clean and fill manometers.	6 Months
23. Remove, clean and check all safety devices for proper operation.	6 Months
24. Flush and refill digester dome seals.	6 Months
25. Sound digester by sampling from bottom up at 5-foot intervals.	6 Months
26. Remove digester from service and clean and repair unit.	3-8 Years
D. Sludge Withdrawal	
1. Check volatile content of bottom sludge, if below 50% and nuisance odors not present it should be ready to remove.	Weekly
2. Frequency of removal will vary with method of dewatering and/or disposal. Some plants that haul wet sludge to land sites or dewater on filters pull out daily. Plants that have drying beds in wet climates may draw out only in summer and fall months.	Variable
3. Collect several samples and composite for calculation of digester efficiency.	When drawing
E. Compressors	
1. Check for proper operation of unit by looking at the oil level, drive belts and discharge pressure.	Daily
F. Piston Type Sludge Pumps	
1. Check for proper operation of pump and motor by looking at the automatic oiler. Make sure that the eccentric is dripping at a regular rate, packing is adjusted properly, drive belt tension is OK. Note the vacuum and discharge pressures and record revolution counter reading and reset.	4 Hours
2. Collect sample of sludge when operating.	Daily
G. Fire Fighting Equipment	
1. Be sure all units are in place and that unit is still within its inspection date.	Monthly
H. First Aid Kit	
1. Be sure they are in place and that all items match the inventory sheet.	Monthly

PREVENTIVE MAINTENANCE CHECK LIST*

1. Exercise the Variable Speed Drive (Raw Sludge Pump)	Weekly
2. Exercise the Variable Speed Drive (Digested Sludge Pump)	Weekly
3. Inspect Pump (Centrifugal, Hot Water Recirculation)	Weekly
4. Inspect Floating Cover for evenness and gas leaks	Weekly
5. Inspect First Aid Kit	Weekly
6. Inspect Pump (Centrifugal, Sludge Recirculation)	Weekly
7. Inspect and clean Motor (Raw Sludge Pump Drive)	Monthly
8. Inspect and lubricate Raw Sludge Pump (Piston Type, Belt Driven)	Monthly
9. Inspect Piping and Exercise Valves	Monthly
10. Inspect and clean Motor (Sludge Recirculation Pump)	Monthly
11. Inspect and clean Motor (Gas Recirculation Compressor)	Monthly
12. Inspect and clean Motor (Digested Sludge Pump Drive)	Monthly
13. Inspect and clean Motor (Gas Storage Compressor)	Monthly
14. Verify accuracy of Raw Sludge Flow Meter (Magnetic)	Monthly
15. Inspect and lubricate Digested Sludge Pump	Monthly
16. Check accuracy of Raw Sludge Density Meter (Nuclear)	Monthly
17. Lubricate Coupling (Hot Water Recirculation)	Quarterly
18. Lubricate Coupling (Sludge Recirculation)	Quarterly
19. Lubricate Coupling (Gas Recirculation)	Quarterly
20. Clean and fill Gas Manometers	Semi-annually
21. Inspect Compressor (Gas Recirculation)	Semi-annually
22. Disassemble and clean Gas Water Traps (Condensate)	Semi-annually
23. Disassemble and clean Flame Arrestors (Gas Piping)	Semi-annually
24. Check for support and leaks on Digester Internal Piping (Gas Mixing)	Semi-annually
25. Inspect and clean Gas Storage Compressor	Semi-annually
26. Clean Heat Exchanger	Semi-annually
27. Disassemble and clean Gas Pressure & Vacuum Relief Valves (Digester Cover)	Semi-annually
28. Check Fire Fighting Equipment	Semi-annually

* **Review the equipment manufacturers' recommended preventive maintenance procedures and schedules. They should be followed. Also refer to your plant's O & M manual for more detail on preventive maintenance for the plant.**

CHEMICALS USED IN DIGESTER CONTROL

Chemical usage in the digester falls into two categories: pH adjustment and metal toxicity control. This section covers pH adjustment. The subject of toxicity is discussed in a separate section on toxic material in Part III, page 3-21.

CONTROL OF pH

Several chemicals are available which can be used as caustic agents in digesters to raise or control pH. Each has advantages and disadvantages. The choice of which one to use largely depends upon availability, cost, storage and handling preference. In all cases of caustic addition, care must be taken to provide mixing. Mixing is essential to be sure that the caustic solution will be distributed throughout the tank contents and prevent localizing the caustic. This section discusses the use of various chemicals in digester operations.

Lime

Lime is one of the most common caustic agents due to its availability, relatively low cost and ease of handling. Lime is usually used in starting a digester because it speeds up gas production and lowers volatile acids concentration. One limitation to the use of lime is its inability to maintain the pH at higher levels than about 6.8. When lime is added to a digester it combines with CO_2, removing CO_2 from the liquid. This combining reaction forms calcium bicarbonate when the digester is below 6.7 or 6.8 and the **bicarbonate alkalinity** is between 500 and 1,000 mg/l (NOTE: This is not total alkalinity). Calcium bicarbonate becomes a buffering agent, neutralizing the acids in the digester and allowing the digester to return to normal.

Too much lime causes insoluble calcium carbonate to form. Like grit, calcium carbonate settles out, takes up space, and may be very difficult to remove. A further disadvantage is that it may create a vacuum in the digester because CO_2 is removed, causing a decrease in gas pressure inside the digester. This occurs when excess lime is added.

If the operator were to continue adding lime after the digester pH has reached between 6.5 and 6.8 and the CO_2 were to continue dropping, a dangerous situation might result. The CO_2 content might drop until it reached about 10% and the pH would start to increase to about 8.0.

As the CO_2 percentage drops, the pressure lowers and a vacuum results. With biological activity continuing, the percent of CO_2 increases, rising again to the 10% level, at which point the pH drops to below 7.0. Additions of lime beyond that necessary to neutralize the acids or indicated by pH are wasteful. They may result in lowered gas pressure, a vacuum inside the tank, and a collapsed cover.

However, it is reported by Perry L. McCarty that some excess calcium carbonate has some benefits: it prevents calcium toxicity and when the pH drops to about 6.5, the insoluble calcium dissolves forming additional bicarbonate alkalinity.

Lime is available in two forms:

1. As unslaked lime, or calcium oxide (CaO),

often called quicklime. It is hygroscopic, which means that it takes up water or moisture quite readily. The major disadvantage is that quicklime must be "slaked" (water must be added in a controlled way) before it can be used. This requires special equipment.

CAUTION: **Always add quicklime to the water to prevent an explosion which may splatter the operator with lime and cause skin burns. Quicklime must be stored in a dry place.**

2. Hydrated lime (calcium hydroxide $Ca(OH)_2$) is the preferred form since it is already slaked and ready to use.

Lime is always mixed with water to form a slurry, using about 100 pounds (45.4 kg) of lime to 50 gallons (189 l) of water before being fed to the digester. Most operators add the lime slurry into a sludge or scum pit at the side of the primary clarifier and pump it along with the sludge.

Lime Dosages. Two quick methods can be used as rough approximations for the amount of lime additions.

1. Apply a dosage of 1 pound of lime for every 10,000 gallons (37850 l) in the digester. This is risky. Too much or too little may be added. A better way is given below.

2. The empirical method:
   PROCEDURE
   a. Obtain a sample of representative sludge (about 5 gallons) from the digester and record the exact amount.

   b. Carefully add calculated amounts of lime to sample until pH reaches about 6.7 or 6.8, then stop. Record total amount of lime used.

   Calculate the amount of lime needed to treat the digester using the results of the above step. The following example shows the calculation.

   Assume 0.1 pounds of lime was required to treat the 5-gallon sample. If the digester volume is 100,000 gallons (378500 l) then,

$$\frac{100,000 \text{ gallons}}{5 \text{ gallons}}$$

   = 20,000 times the sample volume and 20,000 times as much lime would be needed to treat the digester. Therefore 0.1 times 20,000 equals 2,000 pounds (907 kg) of lime required. To get a better estimate, the experiment could be done three times and the results averaged.

Another method is to add enough lime to neutralize the volatile acids. Use the following procedure to find pounds of lime needed.

Calculate the amount of volatile acids in pounds. Volatile acids in mg/l times 8.34 times volume of digester in million gallons equals pounds of lime needed.

For example: Assume volatile acids to be 1,800 mg/l and digester volume to be 150,000 gallons (0.15 million gallons), then, 1,800 times 8.34 times 0.15 million gallons equals 2,252 pounds.

NOTE: The amount of alkalinity already in the digester in this case would be in excess and is considered a cushion.

The following procedures are recommended for lime addition.

1. Begin adding lime if the pH drops below 6.6.

2. Check the vacuum relief device on the digester to be sure it is working (the addition of lime can cause a vacuum inside the tank). Stop lime addition if vacuum relief begins operating and wait 24 hours before starting lime again.

3. Add the lime slurry only while mixing and/or recirculating the digester and continue for at least an hour or more after the last addition. Check the pit frequently.

4. Stop adding lime when pH reaches 6.8.

Anhydrous Ammonia

Anhydrous ammonia is a gas and is available in pressurized cylinders. It may be used for pH adjustment under controlled conditions. However, lime, or other caustics, are recommended for the smaller plants for safety reasons.

Several precautions are noted below for those using anhydrous ammonia:

1. There is the possibility of ammonia toxicity if the neutral pH is overshot. The toxic level depends on other buffering agents in the digester but the concentration should not exceed 1,400 mg/l as N in any case.

2. The gas cylinders should be handled using all the precautions normally employed with gases under pressure, i.e., do not drop or strike with sharp objects, keep away from excessive heat and use approved regulating valves.

Several feeding procedures are noted below.

1. Make up tight ammonia connections from cylinder to aluminum pipe. Insert the pipe through a thief hole in the top of the digester. The pipe should go to a depth of 10-15 feet (2.5-3.2 m) in the digester. A 1/8" reducing elbow can be attached to the lower end of the pipe so that the pipe can be rotated in a full circle to distribute the gas addition.

2. Make up a connection to a recirculation line which allows gas feed into the sludge while it is being recirculated. The connection may be made using a corporation-cock and necessary fittings to mate with the feed system. Precautions to be observed include:
   - a. Use materials in connection and feed piping that are not affected by ammonia. DO NOT use copper or brass fittings.
   - b. Feed ammonia only when sludge is circulating and downstream valves are open.

The digester pH should be carefully watched when using ammonia. The greatest danger lies in ammonium toxicity (see Toxic Materials, Part III, page 3-21).

The following example shows how to find the pounds of ammonia needed:

1. Determine desired amount of excess alkalinity. Suggested amount equals 500 mg/l.

2. Determine alkalinity needed to neutralize volatile acids. When alkalinity is expressed as mg/l $CaCO_3$, the amount needed to neutralize volatile acids is:

$$ALK = 0.833 \times VA$$

Example: If the alkalinity equals 2,000 and VA equals 3,000, then the amount of additional buffering alkalinity needed would be:

$$2{,}000 - 0.833(3{,}000) = -500 \text{ mg/l}$$

(NOTE the minus sign shows that this amount is **needed** in addition to excess.)

3. Determine amount of ammonia needed by the following formula:

lbs. of 100% NH_3
= 2.78 × vol. of dig. in gal.
× needed alkalinity in mg/l $CaCO_3$
(excess + buffering) ÷ 1,000,000.

a. Assume:

Digester volume	**250,000 gal.**
Alkalinity	**2,000 mg/l**
Volatile acids	**3,000 mg/l**
Excess alkalinity desired	**500 mg/l**

b. Find amount of alkalinity needed to neutralize the VA. (See Step 2 above.)

c. Find total alkalinity needed

$500 + 500 = 1{,}000$ mg/l as $CaCO_3$

4. Find amount of ammonia needed

lbs. of 100% NH_3

= 2.78 times dig. vol. in gal.

times mg/l alk. needed per 1,000,000 gal.

= 2.78 times 250,000 times 1,000 per 1,000,000 gal.

= 2.78 times .25 times 1,000

= 695 lbs. (315 kg)

5. Commercial anhydrous ammonia is about 80% ammonia. Correct for this amount by:

$$\frac{100\%}{80\%} \times 695 = 869 \text{ lbs. (537 kg) 80\% ammonia}$$

6. Find feed rate.

The feed rate should be about 0.85 lb./1,000 gal. (0.102 kg/1000 l) digester volume per hr.) at a pressure of 50 psi (345 kN/m²).

Feed rate

$$= 0.85 \text{ lb.} \times \frac{250{,}000}{1{,}000} \text{ per hour}$$

$$= 212 \text{ lbs./hr. (96 kg/hr.)}$$

Other Chemicals Used for pH Adjustment

A table entitled "Chemicals Used in Control of Digesters," Table II-4 on page 2-38, lists other chemicals used for pH control in addition to chemicals used for other purposes.

In order to use the pH control chemicals, it is helpful to know how to figure the amount needed based on the alkalinity expressed as $CaCO_3$.

Two factors must be considered, the **equivalent weight** of the chemical and the percent available. The following example shows how to make the calculation using the information given.

Digester volume	250,000 gal
Volatile acids (VA)	3,000 mg/l
Chemical bicarbonate of soda	
Equiv. wt. from Table	84
% available from supplier	68%
$CaCO_3$ equiv. wt.	100
Alkalinity needed/lb. VA	0.833

1. Find pounds of volatile acids in the digester

$3{,}000 \times 8.34 \times 0.25 = 6{,}255$ lbs. (2838 kg) VA

2. Find pounds of $CaCO_3$ needed

$6{,}255 \times 0.833 = 5{,}210$ lbs (2364 kg) $CaCO_3$

3. Find pounds 100% bicarbonate ($NaHCO_3$) needed

$$5{,}120 \text{ lbs. } CaCO_3$$

$$\text{times } \frac{\text{equiv. wt. } NaHCO_3}{\text{equiv. wt. } CaCO_3}$$

$$\text{equals lbs. 100\% } NaHCO_3$$

$$5{,}120 \text{ times } \frac{84}{100}$$

equals 4,376 lbs. (1985 kg) 100% $NaHCO_3$

4. The amount available is 68% not 100%, therefore:

$$4{,}376 \text{ times } \frac{100\%}{\text{available \%}} = 4{,}376 \times \frac{100}{68}$$

= 6,435 lbs. (6920 kg) of 68% $NaHCO_3$

As a practical matter, the total amount needed would not be added at one time but rather spread out over three to four days in equal increments. Volatile acids, alkalinity and pH should be monitored in the active zone of the digester and records kept on the progress toward recovery.

Another way to estimate chemical dosage is given in conjunction with Table II-3 where the percent concentration of acid in the digester is used to find the appropriate amount of neutralizing chemical.

Using the same information as in the previous example and assuming liquid caustic soda (NaOH) is to be used, the steps would be as follows.

1. The pounds of acid were

3,000 x 8.34 x 0.25 = 6,255 lbs. (2838 kg) VA

2. Pounds per 100 gallons of digester volume

$$\frac{\text{lb. VA}}{\text{vol. dig./100}} = \frac{\text{6,255 lb. VA}}{\text{250,000/100 gal}}$$

$$= \frac{\text{2.5 lb.}}{\text{100 gal}} \left(\frac{\text{0.3 kg}}{\text{100 l}}\right)$$

3. Read across from the column "pounds of acid per 100 gal." that reads 2.5 to the column "NaOH liquid caustic soda" which reads 3.32 lbs.

4. Find total number of pounds needed

$$\frac{\text{3.32 lbs. NaOH}}{\text{100 gal}} \times \text{dig. cap. in gal}$$

$$\frac{3.32}{100} \times 250{,}000 = \text{8,300 lbs. (3766 kg)}$$

NaOH

Approximate amounts of other chemicals can be determined by the same method using the information in Table II-3.

Note:
1 kg = 2.205 lb.
1 l = 0.264 gal.

TABLE II-3
QUANTITIES OF VARIOUS ALKALIES REQUIRED TO NEUTRALIZE VOLATILE ACIDS

Actual lbs. of Acid per 100 gals.	NH_3 Anydrous Ammonia lbs.	NH_4OH Aqua Ammonia gals.	Na_2CO_3 Anhydrous Soda Ash lbs.	NaOH Liquid Caustic Soda, lbs.	NaOH Flake Caustic Soda, lbs.
834	236	197	.736	1.11	.555
1.67	472	216	1.47	2.22	1.11
2.50	708	322	2.21	3.32	1.66
3.34	944	429	2.94	4.44	2.22
4.17	1.18	536	3.68	5.54	2.77
5.00	1.42	645	4.43	6.68	3.34
5.84	1.65	.750	5.14	7.76	3.88
6.67	1.89	.859	5.89	8.88	4.44
7.51	2.12	.963	6.61	9.96	4.98
8.34	2.36	1.07	7.36	11.10	5.55
16.71	4.73	2.15	14.74	22.24	11.12
25.10	7.11	3.23	22.16	33.42	16.71
33.51	9.49	4.31	29.58	44.60	22.30
41.96	11.88	5.40	36.84	55.84	27.92
50.42	14.27	6.49	44.48	67.06	33.53
84.5	23.92	10.87	74.56	112.42	56.21
171.3	48.5	22.05	151.17	227.96	113.98

Table II-4 CHEMICALS USED TO CONTROL DIGESTION

CHEMICAL NAME		COMMERCIAL NAME	USE/APPLICATION	STORAGE AND HANDLING
Calcium Oxide	Formula CaO Equiv. wt. 56	Unslaked Lime Quick Lime	To raise pH. Must be slaked before using to form a slurry. Do not apply water to quick lime — it explodes.	Comes in 50-pound bags as a powder. Splashing lime will cause skin burns. Wear rubber gloves. Dusty, slakes on standing in air.
Calcium Hydroxide	Formula $Ca(OH)_2$ Equiv. wt. 74	Slaked Lime High Calcium Lime Hydrated Lime	To raise digester pH.	Dusty, keeps better in storage than quick lime. Splashing slurry may cause skin irritation, wear gloves.
Anhydrous Ammonia	Formula NH_3 Equiv. wt. 17	Anhydrous Ammonia or agricultural fertilizer	To raise digester pH. Needs close control to avoid excessive pH and ammonia toxicity. Ammonia is toxic at concentrations of 1500-1600 mg/l as N.	Comes in cylinders or tanks as a gas. Do not store near chlorine. Keep temperatures below 70°F. (21°C.) Store in a well-ventilated room. Have masks available. Wear rubber gloves. An irritating alkali, it can cause severe skin burns on contact. Ammonia is corrosive to copper. Do not neutralize with acid. Use water.
Ammonium Hydroxide	Formula NH_4OH Equiv. wt. 35	Liquid Ammonia used as an agriculture fertilizer	To raise digester pH	Is available in liquid form from farm supply firms.
Sodium Carbonate	Formula Na_2CO_3 Equiv. wt. 106	Soda Ash	pH control. Combines with CO_2 to form calcium bicarbonate. No ecological problems.	Comes in 50-pound bags as a powder. It is highly soluble in water. As a caustic, it will cause skin burns. Its chief problem is as an eye irritant. Use rubber gloves and mask or goggles.
Sodium Bicarbonate	Formula $NaHCO_3$ Equiv. wt. 84	Bicarbonate of Soda	pH control.	Comes in 50-pound bags as powder. Requires same precautions as soda ash.

Sodium Hydroxide	Formula NaOH Equiv. wt. 40	Lye Caustic Soda	pH control. Combines with water and CO_2 to form sodium bicarbonate. Obtain special handling and use instructions from supplier before using.	Shipped in steel drums or in bags. Available in flake or crystals or as a liquid. Normally purchased in flake or crystals due to special handling problems. Use rubber gloves, cotton clothing and goggles or face shields. Neutralize with water only.
Ferrous Sulfate	Formula $FeSO_4$	Ferrous Sulfate	To precipitate heavy metals. Contact supplier for dosages and application.	Obtain handling and safety instructions from supplier.
Ferric Sulfate	Formula $Fe_2(SO_4)_3$	Ferrisul-Monsanto Corp. Ferriclear-Stauffer Chemical Co.	To precipitate heavy metals. Contact supplier for dosages and application.	Obtain handling and safety instructions from supplier.
Hydrogen Peroxide	Formula H_2O_2	Hydrogen Peroxide	For odor control in sludge handling facilities (beds, etc.) when emptying sour digesters. Add at rate of 1.5 lb. H_2O_2 per lb. sulfide. (1.5 kg/kg)	Shipped in 50-gallon (189 l) drums as a liquid. Use a 30 or 35% solution to avoid severe burns. Wear rubber gloves and face shield. Neutralize with water. See supplier instructions before using.

PART 3

POTPOURRI

MANPOWER REQUIREMENTS FOR ANAEROBIC DIGESTER OPERATION AND MAINTENANCE

SAFETY

DIGESTER START-UP, INTERRUPTION AND CLEANING

TOXIC MATERIALS

CASE HISTORIES

GADGETS

MANPOWER REQUIREMENTS FOR ANAEROBIC DIGESTER OPERATION AND MAINTENANCE

INTRODUCTION

Hiring of personnel, based solely on their abilities for operation of anaerobic digesters, is seldom done except in very large plants. Nevertheless, a plant that has digesters must also employ people with the necessary skill to maintain good operation.

This section covers several aspects of staffing for operation and maintenance of digesters. The three areas of discussion include procedures for estimating time requirements, job descriptions and some aspects of training associated with digesters.

ESTIMATING TIME REQUIREMENTS

Three prime references compiled for EPA are available for estimating manpower requirements for treatment plants. These include sections that deal with anaerobic digestion specifically and give man-hour estimates on an annual basis.

The three publications are:

1. *Estimating Staffing for Municipal Wastewater Treatment Facilities*, EPA Report, Contract No. 68-01-0328 (March 1973).

2. *Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities*, EPA Report, Contract No. 14-12-462 (October 1971).

3. *Estimating Laboratory Needs for Municipal Wastewater Treatment Facilities*, EPA Report, Contract No. 68-01-0328 (June 1973).

The first two publications use graphs to assist in arriving at annual man-hours required for various unit processes including digestion. The first is most useful for plants from 0.5-25 mgd, the second for 2-100 mgd.

A method is given in the first reference for making estimates based on specific plant conditions. The second publication breaks manpower requirements into the areas of raw sludge pumping, sludge holding tanks, anaerobic digesters and sludge beds.

In considering the number of man-hours required for a specific segment of the plant, remember that personnel perform dual functions. The operator may pick up samples from the final clarifier and check the condition of the supernatant while making a general inspection of the plant. In doing this, it is difficult to separate the number of hours per day spent specifically on digestion. However, the estimates will give some guidance on manpower needs, particularly to operators facing plant expansion which includes expanded digestion facilities.

Generally, the activities to consider when estimating time spent specifically on digester operation and maintenance include:

1. Sample collection and analyses.

2. Equipment maintenance on units directly associated with tank structures and mechanical devices used in the digestion process.

3. Operation activities associated with monitoring and/or changing raw sludge pump-

ing supernatant withdrawal, sludge recirculation, etc. The Equipment and Process Operation Guides in Part 2 of this manual will help identify all the functions operators must perform.

Using information from the above three sources to estimate time requirements for operation and maintenance functions, each operator should be able to arrive at information specific to his own treatment plant.

JOB DESCRIPTIONS

Many of the functions performed by operation personnel in other areas of the plant are duplicated in digester operation. In addition to equipment surveillance and routine process adjustments, an understanding of the biological process is helpful to give a reason for the changes that may be required.

Detailed job descriptions for specific job positions in treatment plants are listed in the EPA publication, *Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities*, pages 149-190 (cited in the previous section).

Three major categories summarize the tasks performed by personnel necessary for most plants. These are Operations Tasks, Maintenance Tasks and Laboratory Tasks. A summary from the EPA publication, *Estimating Staffing for Municipal Wastewater Treatment Facilities*, pages E-1, E-2 and E-4 (with specific adaptations), presents a good overview of digester personnel responsibilities. In small plants, part of, or all these functions may be done by one person, while larger plants will divide them between several persons.

Operations Tasks

Included in these tasks are various activities that are commonly identified with the mechanics of plant operation. The following are examples:

1. Operation of process equipment, valves, sludge pumps, mixers and boilers.

2. Cleaning of equipment, bar screens, and other items necessary for proper unit process function.

3. Taking sludge samples as required.

4. Operation of electrical controls (timers, etc.).

5. Monitoring of gauges, meters and control panels.

6. Monitoring of sludge and supernatant quality.

Maintenance Tasks

Maintenance has been divided into two types: preventive and corrective maintenance. These can be defined as "what you do to keep equipment from breaking (preventive), and what you do to fix broken equipment (corrective)." Some of the activities you might perform in both types of maintenance are the following:

1. Lubricate equipment and check for equipment malfunctions.

2. Replace packing in sludge pumps, sludge mixers, and gas and sludge valves.

3. Service and replace bearings in motors and other equipment.

4. Install and start up new equipment.

5. Clean out pipes (sludge lines).

6. Do some minor plumbing.

7. Do some welding and cutting.

8. Calibrate and repair meters, gauges, and manometers (although this is sometimes done by an electrician or by outside contract).

9. Set up and maintain a regular program of lubrication and replacement of critical parts (bearings).

10. Inspect and service mechanical and electrical control systems (timers, level controllers, etc.).

11. Service and repair gas safety and control devices.

12. Service, inspect and repair sludge heating and mixing equipment.

Laboratory Tasks

In small plants, these tasks may be handled by those spending time at either supervisory or operations tasks. Thus, the supervisor might also be the laboratory technician. Most of the tests associated with digester control do not require a high degree of skill, but do require the ability to obtain repeatable results. Large plants that run metals and nutrient tests will require technically trained personnel. Some of the activities involved in laboratory work are the following:

1. Collecting samples (sewage and receiving water).

2. Performing laboratory analyses—both simple and complex.

3. Assembling and reporting data obtained from tests.

4. Evaluating data in terms of plant process performance.

5. Preparing common chemical reagents and bacteriological media.

6. Recommending process changes based on laboratory data.

7. Reporting to regulatory agencies on the operation of the plant.

TRAINING DIGESTER OPERATION PERSONNEL

Preparing new personnel and upgrading experienced operators should be ongoing programs in any plant. The resources available to the facility will vary with geographical location and size of community, but each individual responsible for training his personnel should review the following list to see which suggestions are useful for his situation.

Publications

1. Operation and Maintenance Manual for the Plant.

2. This Manual.

3. *Operation of Wastewater Treatment Plants*, Chapter 8, California State University, Sacramento (6000 J Street, Sacramento, California 95819) (1970).

4. *Anaerobic Sludge Digestion–MOP 16*, Water Pollution Control Federation, Washington, D.C. (1967).

5. *Operation of Wastewater Treatment Plants–MOP 11*, Chapter 7, Water Pollution Control Federation, Washington, D.C. (1970).

6. McCarty, P.L., "Anaerobic Waste Treatment Fundamentals–Parts I, II, III and IV," *Public Works*, September p. 107, October p. 123, November p. 91, December p. 95 (1964).

7. Specific magazine articles are listed in Appendix B.

Correspondence Courses

1. The manual listed as item 3 above may also be used as the text for a correspondence course. Information may be obtained from the address noted.

2. Information on a correspondence course prepared for operators in the State of South Carolina may be obtained from:

   Dr. John H. Austin
   Environmental Systems Engineering
   Clemson University
   Clemson, South Carolina 29631

3. Information on correspondence courses from the University of Michigan can be obtained by writing:

   University of Michigan
   Department of Civil Engineering
   Ann Arbor, Michigan 48104

4. Catalogs are available in state and local areas from universities, colleges and community colleges that give instruction and details on correspondence courses.

Other Training Opportunities

1. State sponsored short schools (contact state water pollution control regulatory agency).

2. EPA: each regional office has a Manpower Development and Training Office with information on training opportunities on a regional level.

3. Local community colleges: many community colleges have credit or noncredit courses that are offered either at night or in the day time. Contact the registrar's office for details.

BASIC CAUTIONS

Sludge handling areas and equipment are potentially among the most dangerous in a wastewater treatment plant.

Plant operators should be thoroughly familiar with the problem areas, the safety devices that should be used, the precautions to take and other general rules for working safely.

Pump rooms can accumulate combustible gases, deplete oxygen in the air and be the site of mechanical problems. Pump rooms should be adequately ventilated and provided with low-level oxygen alarms. Pumps should have isolation valves on the suction and discharge side for isolating the unit. Piping connections and equipment should be checked on a frequent basis for leaks.

Dried sludge and powdered chemicals present dust problems. Operators should wear goggles and face-type breathing filters when working with these compounds.

Methane gas is explosive when in contact with air. Avoid mixing air with methane in the range of from 20:1 to 5:1. Maintain a positive pressure in all gas lines to prevent leakage of air into the pipeline. Methane gas is also produced from digested or partially digested sludge found in holding tanks. Therefore, wherever gas may be present, there should be no smoking, sparks or any open flame. Gas detectors must always be used before entering any empty digester.

Electrical installations, including light switches, temporary devices or fixtures must be of the explosionproof type.

Mechanical equipment should always have machine guards in place. Operators must be trained in their proper use and follow all applicable safety rules.

MAINTENANCE SAFETY

The following rules apply at all times whenever working on equipment.

1. Lock out and tag main switch to prevent accidental starting.

2. When working on pumps, be sure suction and discharge valves are fully closed and tagged. Be sure pump is vented and drained.

3. Isolate fuel lines as applicable.

DANGER AREAS

Digester

When you must enter the digester, observe the following basic rules for your protection.

1. Provide adequate ventilation to remove gases and to supply oxygen. Be sure exhaust fan is on.

2. Never enter the digester alone. Always have someone to help in the event of trouble.

3. Use safety harness equipped with safety line.

4. Check for gases with explosimeter.

5. Be extremely careful about footing.

6. Use bucket and rope to lower tools and equipment.

Laboratory Safety

The handling of wastewater and hazardous chemicals creates a potential hazard to the health and safety of individuals in the lab. Danger originates when lab workers fail to use caution in handling these materials, fail to read labels or fail to follow directions as to use and precautions. There always exists the possibility of inadvertent or accidental spills which will require immediate, specific and correct action to minimize a potential hazard. Inhalation of vapors must be avoided since many chemicals or compounds are hazardous in this respect. Most hazards noted in the lab result from inattention, carelessness and poor housekeeping. Some specific rules are listed below:

1. Use chemicals with due respect. Know their properties and how to use them.
2. Be sure each bottle or container is labeled for contents, date, warnings, etc.
3. Read and follow directions carefully.
4. Arrange and store chemicals according to poison, flammability, explosiveness, etc. and in proper areas.
5. Use exhaust ventilation.
6. Wear proper clothing, i.e., rubber gloves, aprons, safety glasses, etc.
7. Know the antidote for poisonous chemicals and keep these posted in lab.
8. When collecting samples, use appropriate sample collecting devices.
9. Use the eye wash in the lab to flush harmful chemicals accidently splashed on the face and the emergency shower to flush chemicals off other parts of the body.

General Plant Safety

All personnel are to assume the responsibility of keeping walking areas safe and free of tools, debris, spills, grease, etc.; checking to see that guards are in place on operating equipment, chain rails are in place and all areas properly lighted.

Electrical Safety

1. Lock out and tag main switch of electrical equipment before working on it.
2. Do not remove tag without first checking with person who initiated the tag.
3. Notify plant superintendent in the event a motor circuit breaker trips out.
4. Only trained plant personnel are to open motor control center panels to perform authorized work.
5. Report and log any unusual motor temperature, noise, vibration, etc.

The safety material presented in this manual is an incomplete summary of general safety procedures. All plant operators should review these practices from time to time. One of the best manuals on plant safety for operators is ***Safety in Wastewater Works MOP No. 1, 1975*** Edition published by the Water Pollution Control Federation.

The following charts summarize details associated with devices and their function in operator safety.

DIGESTER SAFETY DEVICES

ITEMS	SAFETY DEVICES	FUNCTION	MAINTENANCE
GAS			
1. Methane – is explosive in contact with air.	Flame Arrestors	Protect against flashback.	Inspect monthly and clean every 6 months or as experience dictates.
	Thermal Valves	Shut off gas.	
	Water Seal	Vents excessive gas to atmosphere and allows air into digester under vacuum.	
	Pressure Relief Valve	Vents excessive gas pressure.	Inspect every 6 months or more often for proper operation.
	Vacuum Breaker Valve	Brings air into digester to break vacuum.	Inspect every 6 months or more often for proper operation.
	Pressure Regulator	Controls gas pressure on system.	Check diaphragm every 6 months.
	Automatic Gas Pilot Valves	Controls gas burners.	
2. H_2S (hydrogen sulfide) – can be an odorless gas in lethal concentrations.	Gas Detector	To detect presence of H_2S.	Check monthly.
	Self Contained Air Pack	To protect personnel.	Check monthly.
3. General	Good Ventilation	To remove gases from area.	Service according to manufacturer's instructions.
	No smoking, sparks or open flame.	To prevent explosion or fire.	
	Good inspection and maintenance program on gas system and safety devices.	To be sure they work when needed.	
DISEASE TRANSMISSION Such as Skin diseases Typhoid Dysentery	Personal Hygiene Wash basin Showers Rubber clothing Boots, gloves & aprons	To prevent spread of diseases into body.	Check for corrosion and proper water pressure. Operate showers weekly. Check water flow rate annually.

DIGESTER SAFETY DEVICES (Cont.)

ITEMS	SAFETY DEVICES	FUNCTION	MAINTENANCE
CHEMICALS Danger from dust, inflammation and burns.	Self-contained air pack Rubber gloves and aprons Face dust mask Eye wash Showers	To provide a noncontaminated source of air for a limited period of time in locations with deficient oxygen and/or lethal gases.	Check air pack monthly. Check batteries each time it is used.
PHYSICAL INJURY Danger from falls and moving of equipment.	Machine guards Railings and safety chains Safety ladders Safety harness Housekeeping Lighting First aid kit	To prevent physical injury.	Check machine guards, safety chains and lighting daily. Perform housekeeping continually. Check ladders and harness each time used. Check first aid kit weekly.
ELECTRICAL Danger from shock and fire.	Electrical lock-out tags Rubber mats Maintenance program	To prevent accidental turning on of equipment. To prevent electrical shock by grounding through body. To keep equipment clean.	Provide a sound maintenance program.
FIRE	Portable fire extinguishers	To put out fires.	Check monthly. Invite representatives from fire department to set up routine for testing and checking fire protection equipment.

SAFETY RULES AND REGULATIONS FOR THE PREVENTION OF ACCIDENTS

1. **Protect your head! Wear a hard hat at all times.** Except in the office, lab or break areas.

2. **Prevent falling! Keep all areas clear and clean.**
   a. Pick up all loose objects, tools, trash, ladders, hose, etc.
   b. Clean up all oil or grease spills immediately.

3. **Prevent body infections and disease!**
   a. Do wash hands.
   b. Do wear gloves when working on or with sewage equipment or collecting samples.
   c. Do shower and change clothing before going home.

4. **Do use common sense when moving or lifting heavy objects.**
   a. Use proper equipment.
   b. Lift with your legs—not your back.

5. **Do not RUN to answer the telephone!**

6. **Use handrails on stairways.**

7. **NEVER work on equipment without:**
   a. Locking it out at push button or circuit breaker.
   b. Tagging main circuit breaker.

8. **Know where safety equipment is and how to USE it!**

9. **Know locations of all fire extinguishers and how to use them!**

10. **All injuries, even scratches or skin abrasions, MUST be reported and first aid given!**

11. **BE ALERT to safety conditions around the plant!**
    If something is out of place or not working, fix it! Examples: light bulbs burned out, safety chains not in place, padlocked equipment not locked.

DIGESTER STARTUP, INTERRUPTION AND CLEANING

INTRODUCTION

Digester operation may be a difficult enough problem on a particular facility; however, the procedure is further complicated by the need to start new digesters, shut down and clean an existing vessel. Although the operation of the tank can be managed to prevent hazards, this chapter will discuss some of the methods used by operators in each of the above situations.

STARTING A NEW DIGESTER

The goal in starting new digesters is to begin digesting the organic matter as soon as possible and produce burnable gas under stable operating conditions. A stable condition usually means the volatile acid to alkalinity ratio and the pH are maintained without continued addition of chemicals. Several considerations will influence the best startup method. These include:

1. Availability of seed sludge (either from some other operating digester)
2. Ability to control feed rate
3. Type of feed
4. Availability of other digesters and condition of their contents

Several methods will be discussed briefly, as follows:

- Single Digester – No Seed Available
- Multiple Digesters – No Seed Available
- Single Digester – Seed Available
- Multiple Digesters – Seed Available
- High Rate Digesters – No Seed

Single Digester – No Seed Available

1. Fill digester with raw sludge and sewage by pumping continuously to level that will cause a seal to be formed around the floating cover. In a fixed cover tank, fill up to the supernatant overflow. This will be defined as the operating level.

2. When the tank is full, begin heating the contents to bring the temperature to approximately 95 degrees Fahrenheit (35 degrees centigrade) as rapidly as possible.

3. Begin mixing and/or recirculating at maximum rate when operating level is reached.

4. Begin feeding raw sludge at a uniform rate. Gradual addition over 24 hours is preferable. Maximum feed rate would be an even feed over an 8-hour period.

5. Records should be kept and results put in a graph form for the following information:
   a. Quantity of Raw Sludge Fed
   b. Raw Sludge, Total and Volatile Solids
   c. Total and Volatile Solids of Digester Contents
   d. Volatile Acids, Alkalinity and pH of Contents
   e. Temperature, Gas Production, CO_2 Content of Gas

The section on Data Review and Graphing in Appendix G discusses the use of lab results and graphing of data.

6. At low feeding rates, it may be possible to bring the tank into normal operation without adding anything for pH control. If VA/Alk ratio rises to 0.8 or more and pH is below 6.5, addition of some buffering agent such as lime or soda ash should be considered. The amounts and conditions for use are discussed in the section entitled Chemical Usage in Digester Control, page 2-33.

7. Fairly stable conditions should be reached in 30 to 40 days if loadings do not exceed 0.06 lb./day/cu. ft. (0.96 kg/day/m^3).

The addition of chemicals for pH control is a hotly debated subject among operation personnel. However, chemicals can be the means of preventing digester failure if used properly. If the operator is in a location where chemicals are not available or has definite reservations about their use, there are alternatives available. Feed as much sludge as the digester will handle without going below pH 6.5 and/or above VA/Alk ratio of 0.8 and:

1. Haul the balance to another treatment plant in a tank truck or septic tank pump truck, or:

2. If aeration capacity is available, aerobically digest the extra sludge. The stabilized sludge may be added later, or if volatile content is reduced to approximately 60 percent, it may be disposed of directly on drying beds or applied to other land disposal sites, if available.

Multiple Digesters—No Seed Available

Follow the procedure cited in Single Digester—No Seed Available, except both tanks should be filled with sewage. Raw sludge may be fed to the primary, letting the supernatant transfer to the secondary. The secondary may be used as a means of keeping the loading to the primary low [less than 0.06 lb./cu.ft./day (0.96 kg/m^3/day)] as follows:

1. Ten to twenty percent of the raw sludge may be directed to the secondary for several weeks or more if necessary. If, after two to three weeks, the bottom sludge from the secondary has higher alkalinity and pH than the primary, this may be recycled back to the primary to act as a buffer.

2. As the primary approaches stable condition, more bottom secondary sludge may be recycled back to the primary to increase the buffering capacity and increase gas production.

Single Digester—Seed Available

If sufficient buffered seed sludge is available from a nearby treatment plant, this can reduce the start-up time to two weeks or less. The amount of seed required is about 20 times the anticipated volatile solids in the raw sludge. Example: If it is estimated that the raw sludge will be about 1,000 gallons per day (3785 l per day) at 4 percent solids and 80 percent volatile, then the amount of volatile solids in the feed would be:

$$0.04 \times 1{,}000 \times 0.8 \times 8.34 = 270 \text{ lbs } (122 \text{ kg})$$

Thus, 270 times 20 equals 5,400 pounds (2450 kg) of volatile solids would be needed as seed sludge.

If the seed sludge averages 5 percent solids and 50 percent volatile, the amount to be hauled would be:

$$\frac{5{,}400}{0.05 \times 8.34 \times 0.5} = \text{approx. } 25{,}900 \text{ gal}$$

The procedure would be as follows:

1. Haul seed sludge and transfer into digester directly, if possible.

2. Fill tank with sewage and follow steps 2 through 6 of Single Digester—No Seed Available.

3. No thinning should be necessary if raw sludge is fed evenly. However, if records show thinning is needed, some sludge should be hauled to the plant where the seed was obtained when more seed is hauled to replace sludge drawn out.

Multiple Digesters–Seed Available

In a new plant with multiple tanks, starting up with seed available from another plant is essentially the same as under Single Digester–Seed Available. The same recycle capability as discussed under Multiple Digesters–No Seed Available should be applied.

With the availability of more than one tank, it is possible to start each by loading between tanks for better seeding process of the primary tank. Once stable conditions may be established in the primary tank, future startups can be accomplished using seed from an operating primary digester.

High-Rate Digesters–No Seed

The term "high-rate" generally refers to the rate of loading and/or detention time in the tank. Generally, detention times of 10 to 15 days are considered in the high-rate range.

Startup can be accomplished in 30 to 60 days using the method detailed under Single Digester–No Seed Available, if mixing is continuous and pH is adjusted and maintained in the range of 6.8 to 7.2. Feed rates should be maintained that would allow a hydraulic detention time of not less than 30 days until normal levels of gas production are reached.

Some general rules that apply in all cases of startup are noted below.

1. When the desired temperature is reached, it should be held within plus or minus one degree Fahrenheit continuously.

2. Maximum mixing should be used to keep the volatile material in contact with the bacteria and prevent raw sludge pockets from collecting in the tank bottom.

3. Foaming may result if too much feed is added and mixing is not adequate. If it is not possible to mix continuously, mix during and after feeding.

4. Gas production should start to increase within a few days of startup and rise rapidly as volatile solids decrease. Gas production normally will reach some maximum point, then decrease to a stable level.

5. Best results in startup will be obtained if volatile acids, alkalinity, pH, loading and gas production are monitored daily in large plants, twice weekly in small plants and results plotted on a graph. Trends can be spotted and corrections made before problems develop.

INTERRUPTION OF NORMAL PROCESS WITHOUT DRAINING

There are times when digester operation must be interrupted for varying periods of time when it is neither possible nor desirable to empty the tank. When this is necessary, certain precautions need to be taken and procedures followed when putting the digester back in operation. Several situations are described.

- Mechanical Repairs
- Temperature Loss
- Hydraulic Washout
- Organic Overload
- Toxic Loading

Mechanical Repairs

Pumping equipment failure may interrupt the process for several hours or up to a period of several days. Mixing and heating should be continued even though feed to the digester has been stopped. Sludge may be stored in the clarifier for 24 to 48 hours in warm weather or longer in cold weather.

When normal feeding is resumed, care must be taken not to slug the digester. Restarting will be assisted by maximum mixing. Frequent monitoring of volatile acids will indicate digester reaction to restarting. High feeding rates should be spread out over as long a time period as possible.

Repairs to equipment may require opening access holes in the digester dome. In that case, precautions against explosion and poor breathing conditions must be taken. When the digester is producing gas, pressures above atmospheric normally will prevent air from entering the tank. However, the first gas removed from the tank following the resumption of operation should be vented to the atmosphere for two to three hours before ignition.

Temperature Loss

When normal heating is interrupted and the tank contents cool down, gas production will normally drop off. The following items should be considered in this situation.

1. Feed rate should be kept as low as possible.

2. Only the thickest sludge should be pumped. (Clarifier scum, if it is normally fed to the digester, might be removed and buried until operation has resumed.)

3. Mixing should be confined to the lower portion of the tank to prevent heat loss through the dome.

4. When normal operation has resumed, and temperature loss is not more than 10 or 15 degrees, bring heat up at about one to two degrees per day and maintain mixing at the maximum rate.

5. Monitor volatile acids and be prepared for high gas production and possible foaming as a result of available food digesting at faster reaction rates. Correct pH by recirculating from the bottom of another digester or with chemicals if necessary.

Hydraulic Washout

This occurs when abnormal amounts of thin sludge are received due to industrial waste, or accidental overpumping. Digester contents are replaced with water. The buffering capacity of the contents is lowered and temperature may be reduced.

The digester may react similarly to start-up conditions and the same procedures may be followed to bring it back to normal.

1. Recirculate sludge from an active, well buffered digester, if possible, to bring buffering capacity back to normal.

2. Restore temperature to normal at 1-2 degrees per day.

3. Be prepared to correct pH if necessary.

4. Monitor and record results of the indicator tests. (These are discussed in Part IV, page 4-27 and Part III, page 3-28.)

5. Keep feed rate as low as possible.

Organic Overload

Organic overload may result from solids that settle in the sewer system and are carried to the plant during rain storms. Additionally, some industrial wastes cause increased organic loads. The procedures followed are the same as for hydraulic problems but more care must be taken to prevent foaming. Mixing from the top to the bottom will minimize this problem. Recycling from the active zone or from the bottom of the secondary digester may speed recovery and prevent further problems.

Toxic Loading

Various materials may be toxic to the digester and these are discussed in detail in Part IV, page 4-20 and Appendix G. Two methods of preventing problems or restoring normal operation more rapidly are considered.

1. The preferred method is to isolate the toxic material in the primary clarifier and either neutralize it or haul it out of the plant for disposal.

2. The best procedure to follow in case toxic material is discharged to the digester before discovery is to stop the addition of raw sludge and recycle sludge from another digester back to the affected tank. If no sludge is available for recycle, pump in heated sewage to dilute and displace the tank contents. Dilution with hot sewage pumped through the heat exchanger will maintain the digester temperature while reducing the concentration of the toxic substance.

CLEANING OF DIGESTERS

Operators from various plants were questioned on the frequency of tank cleaning. Answers ranged from every other year to "I've been here for nigh on to 20 years and never cleaned the thing." Most of those who set up procedures for regular cleaning find that operation is more efficient and mechanical problems are reduced. The most frequent cleaning interval of those contacted was approximately three years.

When to clean the tank depends on a number of things which include:

1. Grease accumulation and efficiency of grease removal.
2. Grit accumulation and grit removal efficiency.
3. Types of waste treated.
4. Efficiency of mixing.
5. Structure of the tank.
6. Condition of the internal equipment.
7. Alternative ways of treating sludge when the tank is out of service.

Part IV, page 4-22, describes the method for determining the amount of nondigesting material in the tank that is reducing the available space for digestion. Information is also given beginning on page 2-8 for determining the equipment conditions.

When it is decided that cleaning will be done, other factors must be considered. The following questions should be answered in preparation for the cleaning operation:

1. What will be done with raw sludge while the tank is out of service?
2. Will the job be done using plant personnel, outside contractors, or both?
3. What equipment is available for accomplishing the job?
4. Where will digested sludge be disposed of?

Some possible answers to these questions will be considered in the remainder of this section. The answer to the first depends largely on the availability of more than one tank. For plants using single tanks, this can pose some difficult problems which will be considered below.

- Single Digester Plants
- Multiple Tank Plants

Single Digester Plants

The major problem with cleaning single digester plants is what to do with raw sludge during the cleaning operation. Several alternatives are possible:

1. Concentrate as much as possible and haul by tank truck to a nearby treatment plant. If tank trucks are not available, septic tank pumpers might be used. Costs for the services would be approximately $1.00/100 gal. (based on 1975 cost data), however, some metropolitan areas may run as high as $3-5/100 gal.

2. In activated sludge plants, an available

aeration tank might be converted to a temporary aerobic digester. The sludge can be fed back into the digester over a period of time when operation resumes.

3. A primary clarifier might be converted to a temporary digester if provisions are made for covering with heavy-ply vinyl material and odor control measures are taken.

4. If sufficient land is available and regulatory agency approvals are obtained, a temporary anaerobic lagoon might be set up. This would entail constructing a watertight lagoon or converting an existing tank into a holding pond, filling partially with water and pumping in the sludges that accumulate. Heating might be done with a portable steam cleaner.

5. Lime or other caustic may be used as a stabilization procedure during transfer or as an aid for odor control.

Multiple Tank Plants

Plants with more than one tank are able to distribute feed to other primary tanks or, if there is only one primary and one secondary, the secondary can be used to receive raw sludge.

When one or more tanks are taken out of service, the remaining units will receive higher loads. Closer control will be necessary and adequate mixing must prevail. Where the secondary is used to receive raw sludge, recirculation and/or mixing must be practiced.

In-House or Contract?

Another important consideration is determining who will do the work. Several nationwide firms are actively soliciting work for cleaning digesters and guarantee completion within a specific time period. For a small town with limited facilities or plants that require minimum down time, this is an attractive possibility. Advantages of using plant personnel include their familiarity with piping and their capability to work the operation into the regular schedule. If a plant normally operates a tank truck for sludge disposal, it may be used in the cleaning operation.

To make the decision between using in-plant forces or contracting the job out, the following should be considered:

1. The amount of time the tank can be down.
2. Type of equipment available on-site.
3. Costs of rental equipment.
4. Number of man-hours available from the plant or municipality staff.
5. Disposal site and how sludge will be transported.

An example of performing a job by plant personnel and contracting out is given on page 3-27.

BASIC EQUIPMENT NEEDED FOR CLEANING

The simplest equipment for digester cleaning is an open valve to a drying bed and a washdown hose. The most extensive might include a crane to lift the cover off the digester and a clamshell to scoop the thick sludge out to be hauled away in dump trucks. Most plants will fall between these extremes and the following list shows the types of equipment which may be used in the emptying and cleaning procedure. It may serve as a check list for the operator when preparing for the job of emptying and cleaning the tank. Not all the items would be used in every job but these are presented to give the person responsible a quick method for reviewing those which apply to his particular plant.

1. Sludge line valves. Must be free to operate, not obstructed, and accessible.

2. Sludge lines (permanent). Should be free of obstructions, may require rodding and/or flushing either before, during or after the operation.

3. Sludge lines (temporary). May be aluminum, plastic, steel or heavy duty hose. Should have tight joints and quick couplings, if possible. Minimum size 4" (100 mm); 6" (150 mm) and larger are preferred. (Might be rented from an equipment rental firm, a farm irrigation pipe company, or other sources. Fire departments sometimes have hose available that is being phased out of water service.)

4. Access to inside of digester. Manholes or hatch covers should be available to allow washdown water to be added and men to enter the tank for final cleanup.

5. Explosionproof ventilation fans. Used to exhaust harmful gases and to supply air for breathing when personnel are inside the tank (might be obtained from a fire department).

6. Explosion meter. Used to monitor atmosphere inside the digester. Must be used to verify safety of entrance into tank (might be obtained from a fire department).

7. Ladder with safety apparatus. Manhole rungs built into tank walls may be deteriorated and should be avoided. A sturdy ladder with protection from slipping and tipping should be used.

8. Self-contained breathing apparatus. Used any time work is done before a safe atmosphere exists and whenever entrance into the tank is necessary.

9. Safety harness. Used when entrance is necessary while wearing safety self-contained breathing apparatus and entering a tank partially filled with sludge.

10. Explosionproof lights. Used inside the tank at any time.

11. Source of water. Should be air-gapped and capable of supplying a pressure in excess of 60 psi (400 kN/m^2) (up to 100 psi (700 kN/m^2) is preferred).

12. Washdown water hose. Should be 1-inch (25 mm) or larger.

13. Fire hose type nozzle with shutoff. Should be 1-inch (25 mm) or larger.

14. Auxiliary washdown water pump. May be used when other suitable sources are not available. The pump can take suction from the final effluent; precautions must then be taken to warn workmen that it is non-potable water. (Fire departments may have surplus hose available.)

15. Sludge pumps (fixed). The operator should review pump and piping arrangements for emptying the digester. Recirculation pumps may be used for part of the draining procedure. Generally, these pumps have a higher volume output than positive displacement pumps used for heavy solids handling.

16. Sludge pumps (portable). Portable pumps may be placed in several configurations and may be positive displacement or centrifugal with special adapted impellers. Pump motor ratings should be checked for compatibility with available power sources (single-phase, three-phase, etc.). They may be temporarily wired into circuits used by equipment that will be out of service during the cleaning operation, such as mixers, recirculation pumps, etc. (Pumps may be on-site, borrowed from nearby plants, or rented. In some cases where several tanks are involved, it may pay to purchase a portable dewatering pump.) The following are several possible configurations for pumps.

    a. Mounted in-line, to pull from existing suction line and discharge through fixed discharge.

b. Mounted in-line, to pull from existing suction and discharge through a portable line.

c. Mounted at some location to take suction from portable suction line and pump into disposal site or portable discharge line. Motors or engines must be explosionproof if located near openings in the digester cover. (Gas driven pumps must be located so that fumes are not drawn into the tanks through ventilation systems when people are inside the tank.)

d. Open impeller pumps, with special cutter blades and explosionproof motors may be lowered into the tank and flexible discharge hose attached to temporary or permanent discharge lines. These may be submersible or nonsubmersible types.

Normally, the pump is lowered through the manhole using a tripod or other safe and controlled method of keeping the pump at the desired level.

e. Positive displacement or centrifugal pumps may be lowered into the tanks and placed on a temporary platform or tank floor to provide minimum suction. Discharge may be either through fixed or portable lines.

17. Turret nozzle. Firefighting equipment supply houses have special turret nozzle apparatuses that may be adapted for use in digesters. These may be programmed to direct high pressure water to localized portions of the tank automatically. These are particularly useful to plants with more than two digesters and where cleaning is done at two- to three-year intervals.

18. Tripod or hoist. These may be mounted on the tank roof above the manhole to facilitate removal of equipment, and raising or lowering the dewatering pump (it might be rented or obtained from a machine shop or other municipal department).

19. Tank truck. If this is not a part of on-site equipment, rental companies in larger cities may be able to provide this equipment. Charges are based on distance to disposal site and type of material hauled. Contracts might be made with septic tank pumping firms as well. Nearby treatment plants may also have equipment available. Care must be taken to provide means of handling grit, scum and other debris that might not normally be in sludge hauled from operating tanks under day-to-day conditions.

20. Crane. Mechanized hoist vehicles of various sizes might be used in the cleaning operation. In extreme cases of heavy grit and/or scum accumulations, it may be necessary to remove floating covers and use a clamshell to remove digester contents. Cranes for this operation are normally rented. Care must be taken in removing floating covers to lift them by specific and structurally defined points in order to prevent their collapse. Refer to the tank fabrication or contractor's drawings and contact the supplier to make sure that the correct lift points are used.

The preceding list is summarized in Table III-1 with columns designating equipment that might be used if sludge is handled by:

Column Conditions

A Gravity Flow to an On-site Disposal Area.
B Pump to an On-site Disposal Area.
C Pump to Tank Truck for Off-site Disposal.
D Solidified Solids, Heavy Grease and Grit Accumulation.

The operator can use the blank column to check those items that apply to his plant and may also find additional items that are specific to his plant.

Table III-1
DIGESTER CLEANING CHECK LIST

		A	B	C	D	Other
1.	Sludge line valves	X	X	X	X	
2.	Sludge line (permanent)	X	X	X	X	
3.	Sludge line (temporary)	X	X	X	X	
4.	Digester access	X	X	X	X	
5.	Explosionproof vent fan	X	X	X	X	
6.	Explosion meter	X	X	X	X	
7.	Safe ladder	X	X	X	X	
8.	Self contained breathing apparatus	X	X	X	X	
9.	Safety harness	X	X	X	X	
10.	Explosionproof lights	X	X	X	X	
11.	Water source	X	X	X	X	
12.	Wash down hose	X	X	X	X	
13.	Nozzle with shutoff	X	X	X	X	
14.	Wash water pump	O	X	O	X	
15.	Fixed sludge pump		X	O	X	
16.	Portable sludge pump		X	O	X	
17.	Turret nozzle			O	X	
18.	Tripod or hoist	O	X	O	X	
19.	Tank truck			X	X	
20.	Crane				X	

X = definitely needed
O = possibly needed

A Gravity Flow to an On-site Disposal Area
B Pump to an On-site Disposal Area
C Pump to Tank Truck for Off-site Disposal
D Solidified Solids, Heavy Grease and Grit Accumulation

SAFETY PRECAUTIONS

Precautions must be observed to prevent the following:

1. Falls (use of safe ladders, harness, etc.)
2. Infection (basic hygiene and protection of open cuts)
3. Injuries during use of equipment (staying clear of moving equipment, staying out from under objects overhead, and wearing a safety helmet).
4. Asphyxiation or suffocation (testing atmosphere for oxygen content and use of breathing apparatus).
5. Explosions (testing for explosive conditions, use of spark-free equipment and explosionproof motors).

In conjunction with item 5, the operator must keep in mind the fact that as sludge is pulled out of the tank that air will be pulled in, either through open hatches or through the vacuum relief. The most explosive condition exists when the methane-air mixture is such that methane is between 5-20%. This is the reason the atmosphere in the tank should be monitored and any equipment that could cause sparking must not be used.

When the level of a fixed-cover tank is lowered as when sludge is pulled out for disposal, the gas from another tank should be allowed to equalize in the tank. If air is admitted the gas system should be isolated and vented to the atmosphere to prevent pulling air into the entire multiple tank system.

There must be at least two men on top of a digester for every man inside the tank to remove the worker in case of emergency.

Each job will have special problems which require thinking ahead about safety of individuals and equipment used on the job. Necessary safety considerations must also be included with the list of materials, equipment and procedures which are developed for the job.

GENERAL INFORMATION

Following are some general observations from experience of operators in cleaning tanks which may be of use to personnel working on their first unit.

1. The first consideration is to prepare plans for the disposal of digester contents as well as wash water.
2. The approximate volume of water needed to move the solids to the disposal point (either on-site or to a tank truck) is from two to four times the volume of the digester. As an example, a digester containing 200,000 gallons may require an additional 400,000 to 800,000 gallons of wash water to move the contents to the disposal site.
3. Commercial haulers generally charge \$1.00/100 gallons for hauls for 20 miles or less for disposing of liquid sludge. This will vary from locality to locality.
4. Contractors for cleaning digesters give free estimates and costs may range upward from \$2.00/100 gallons for cleaning the tank and disposing of the sludge on site. Higher costs are necessary if the sludge must be disposed of off site.
5. Little information is available on the use of catch-basin cleaning equipment, but this might be used by enterprising operators for digester cleaning.

TOXIC MATERIALS

INTRODUCTION

Toxic materials entering a digester are those elements or components which cause the bacteria to slow down or which kill them.

Most plants in the United States today have potential toxicity problems, even those plants serving domestic wastes only. Sources of these problems come from accidental spills of petroleum products such as fuel oil, automotive greases and oils, etc. Other plants serving communities connected to various industrial facilities will have potential toxic problems unique to the industrial area. Typical toxic materials include

- Heavy metals discharged by metal plating firms, jewelry manufacturers, tanneries, aircraft manufacturers, etc.
- Sulfides from metal manufacturers, maraschino cherry producers, salt water intrusions, coal mines, and others.
- Phenols and plastic resins from petroleum wastes, furniture manufacturing plants, paint manufacturers or users, and coal tar and gas producers.
- Ammonia from overloading digesters with proteinous wastes.
- Cyanide wastes from metallurgical processes.
- Chemicals from chemical manufacturers.
- Insecticides and fungicides.

GENERAL PLANS AND PROCEDURES

Plants exposed to potential toxic waste discharges will need to develop plans and procedures to identify all potential sources, to prevent these wastes from entering a digester in toxic concentrations, and to implement emergency response programs. The plan should include sufficient laboratory equipment and staffing to perform monitoring and identification procedures. The laboratory staff requirements will vary from plant to plant depending on frequency, variability and complexity of toxic waste discharges. Staffing requirements will also depend on how effective the industrial waste discharge ordinances are.

Depending on need, the necessary lab work may be performed by

1. A lab group headed by a degreed chemist.
2. A lab technician.
3. Outside sources such as
    Community colleges
    High school science departments
    Industrial chemists

Most problems result from the too common practice of dumping concentrated solutions of these toxic materials. Toxic materials entering a digester are those elements or compounds which will produce an **inhibitory** effect leading to a bacterial kill. The best operating plan for any plant is to prevent these materials from entering a digester. The penalty of a digester failure caused by toxicity is a severe one—**emptying the digester, disposing of its contents and starting all over again.**

The most frequent cause for toxic conditions is a slug dose of some toxic material. The only real and effective cure is prevention. Keep toxic materials out of the system. A good industrial waste ordinance which is enforced will help here.

PREVENTION

If toxic concentrations of toxic materials are likely to occur, the plant operator should take the following steps.

1. Set up an industrial inventory, cataloging all connected industries with their types and volumes of wastes. This should include normal concentrations and potential for accidental spills, cleaning or similar discharges.
2. Establish and enforce industrial waste ordinances specifically prohibiting certain untreated toxic discharges.
3. Establish an early warning system for the industry to notify the treatment plant when accidental discharges occur. This means a good public relations program. It's hard to do and hard to get cooperation, but it is essential! Show plant owners or managers what the wastes are doing to the treatment processes.
4. Establish a training program to teach operators how to look for the presence of toxic materials in the plant's influent.
5. Establish a laboratory sampling and testing program to monitor industrial waste discharges.
6. Use holding tanks to contain the toxic wastes. In many plants, this may be difficult to do. However, take a close look at all of the possibilities. You may find a way to isolate the suspected toxic material in the primary clarifier, this is a particularly good solution if you have several primary clarifiers.
7. Preplan actions to respond to a toxic waste. For example
   a. Isolate and hold the waste (see item 6 above).
   b. Dilute the waste below the toxic level by
      - Using seed sludge from a secondary digester. NOTE: this action tends to spread the toxic material to both tanks and both tanks may be affected.
      - Using dilution water.
   c. Forming an insoluble precipitate.
   d. Using another compound which will react with the toxic element to form less harmful compounds. These are called **antagonistic compounds** because they neutralize the toxic effect.
8. If the plant lacks the necessary lab equipment or personnel to investigate and identify toxic materials, use any available resources to do the tests. Other resources include

   a. High school science instructors and laboratories
   b. Community college instructors and laboratories
   c. Commercial laboratories
9. Improve digester operation—the tolerance level of digesters to toxic materials is increased when digesters are in a healthy condition. This means a pH of 6.8 to 7.2 and plenty of buffering alkalinity.

The rest of this section discusses different kinds of toxic substances and some of the things that can be done to control their effects on the process.

Alkali and Alkaline Earth Salt Toxicity

Inhibitory concentrations of sodium, potassium, calcium and magnesium normally come from industrial wastes, but sometimes the operator causes them by overcorrecting a pH problem. The following table lists the effects of different concentrations of these salts on digesting sludge.

Table III-2
STIMULATORY AND INHIBITORY CONCENTRATIONS OF ALKALI AND ALKALINE EARTH CATIONS

	Concentrations in mg/l		
Cation	Stimulatory	Moderately Inhibitory	Strongly Inhibitory
Sodium	100-200	3500-5500	8,000
Potassium	200-400	2500-4500	12,000
Calcium	100-200	2500-4500	8,000
Magnesium	75-150	1000-1500	3,000

Stimulatory concentrations are desirable because they improve the process and are often used for control. Moderately inhibitory concentrations can be tolerated except when introduced in slug doses. Process recovery may take up to a week. Strongly inhibitory concentrations cannot be tolerated. Usually the digester must be emptied and restarted because the process cannot recover.

If one of these elements is present in toxic concentrations, it can be controlled by adding one of the others as an antagonistic element. In an article appearing in ***Public Works***, November 1964, Perry L. McCarty reports, "For example, if 7,000 mg/l of sodium were present, it is possible to add 300 mg/l of potassium which will reduce the toxic effect by 80 percent. Then, if 150 mg/l of calcium were added, the toxic effect would be eliminated. Antagonists are best added as chloride salts. If these are not available or are too costly, the best method would be dilution."

Ammonia Toxicity

Concentrations of ammonia between 1,500 and 3,000 mg/l can be inhibitory if the digester pH is greater than 7.4. Under these conditions, however, the volatile acid production will increase, decreasing the pH. This may relieve the inhibitory effect. The volatile acid concentration will remain at a high level unless the pH is reduced by adding hydrochloric acid (HCl). The HCl should be added until the pH is about 7.0. Add the HCl slowly to keep the pH from going below 7.0.

At concentrations above 3,000 mg/l, ammonia becomes toxic enough to cause digester failure regardless of pH. The best remedy is to dilute the digester by withdrawing supernatant or digested sludges and adding settled sewage.

Sulfide Toxicity

Sulfides in a digester come from the normal amounts contained in domestic wastewater, from metallurgical industries as sulfate salts, and from anaerobic protein decomposition. They are in two forms: insoluble heavy metal sulfides that precipitate from the solution and are not harmful, and soluble sulfides. Like oxygen, there is a demand for soluble sulfur, which is necessary for bacterial growth. The bacteria can tolerate between 50-100 mg/l of soluble sulfide with little effect. They can handle up to 200 mg/l of soluble sulfides in a continuous operation. Concentrations above 200 mg/l are toxic and must be treated. Treatment consists of:

1. Using iron salts to precipitate sulfides.
2. Dilution of the waste.
3. Identifying, separating, and containing the toxic waste streams.

Heavy Metal Toxicity

Copper, nickel and zinc salts are soluble and are toxic in low concentrations. The tolerable concentration level of these soluble salts depends on the concentration of sulfides in the waste stream. The best method to treat these metals is to add sulfur in the form of sulfuric acid or sulfides. When using these, the operator must be careful not to create a toxic sulfide level by adding too much. Ferric sulfate, commonly called "Ferrisul" may be added to counteract this and also to build up a sulfide reservoir.

J. W. Masselli and others, in an article appearing in the August 1967 ***Water Pollution Control Federation Journal,*** report the use of sulfuric acid for treating metal toxicity.

Sulfuric acid may be purchased in several grades. The cheapest grade is recommended for this use and is designated as Technical Grade 70-90 percent. This acid is generally available from commercial chemical supply firms in 55-gallon (208 l) drums.

Those plants desiring to use sulfuric acid should contact the supply firm and seek their advice on application. Some of the cautions and procedures are given below.

CAUTION: Sulfuric acid should be handled with care using procedures marked on the containers. These include:

1. ***Wearing rubber gloves and goggles.***
2. ***Not getting the solution on clothing or skin.***
3. ***Not pouring water into the acid. A reaction much like pouring water into a hot pan of bacon grease will result.***

The following procedure is outlined for application of the sulfuric acid.

1. If pH is below 7.2, add 11 pounds (24.3 kg) of sodium hydroxide (caustic soda) for each gallon of acid used.
2. Add sulfuric acid in daily doses of 1 gallon/10,000 gallons (1 l/10000 l) in the digester. This adds a concentration of 176 mg/l of acid (173 mg/l sulfate) which will be reduced to 58 mg/l of sulfide. Continue daily doses for three to ten days.

   CAUTION: Do not add water to sulfuric acid!
3. Make sulfide analysis on the digester gas before each daily dose. When the first trace (0.5 mg/l) appears, stop the daily acid additions.
4. This treatment should be effective for up to three months.
5. If continuous treatment is desired, use Ferrisul at daily doses of 1 lb./1,000 gallons (120 g/1000 l) in the digester.

Two other methods may be used if a suitable sulfur compound is not available.

1. Raise the pH contents of the digester to 8.0 by adding soda ash or sodium bicarbonate. Sodium hydroxide may be used, but it may cause the carbon dioxide to go into solution. Watch the CO_2 gas production.
2. Transfer secondary digester sludge to the primary to dilute the incoming sludge and thus reduce the heavy metal concentration.

More information on the subject of toxicity will be found on Troubleshooting Guide 14 in Part I.

LOADING

Controlling Waste Activated Sludge Load to a Digester

A low solids concentration in the digester feed caused detention time problems at a 5 mgd activated sludge plant treating wastes from an industry producing corn chips. This was a result of mixing waste activated with the raw sludge. The problem was solved by converting one of the two primary clarifiers to a thickener. All of the waste activated sludge was then diverted to the new thickener. The thickened waste activated sludge is then separately digested in one primary and one secondary digester while raw sludge is treated in another pair of digesters. By prethickening, the waste activated sludge was concentrated to approximately 3.3 percent solids and with separate digestion the digestion time was increased allowing both systems to function efficiently.

Use of Soda Ash to Control Organic Overloading

Vegetable processing plants seasonally cause over 100 percent increase in the amount of sludge handled at one plant. The operators daily monitor the volatile acids and alkalinity ratio for digester control during the processing season. When the ratio climbs above 0.25, soda ash is added to bring it back into control. As one example, when the ratio reached 0.25, 500 pounds of soda ash were added and then, seven days later when the ratio again approached 0.25, 1,500 pounds were added. Following these two additions, the ratio dropped back down to less than 1 and gas production increased to its previous level.

Hydraulic Overload Control by Using Polymer

A 10 mgd primary plant was hydraulically overloaded and detention times were less than design.

A program was implemented to decrease the volume of sludge being fed to the digester. This was accomplished by adding polymer to the thickener at about 0.2 milligrams per liter dosage to reduce the volume of sludge being pumped. The polymer used was Zimmite No. 651.

Grit Removal in a Single Stage Digester

In a plant that was handling twice its design load, a single stage digester finally failed to operate due to a thick scum blanket and accumulation of grit. This plant operator corrected the problem by opening all possible openings, such as manhole covers and sample vents, and allowing the digester to sit idle with no recirculation. The scum blanket formed a cover thick enough to prevent odors in the area.

In order to move excess grit from the bottom, an air compressor with a long pipe was obtained and air was fed into the bottom of the digester while sludge was being drawn off to the beds. If tried in other locations, this procedure might be safer using steam.

Breaking up a Scum Blanket with a Pump

How can a scum blanket be broken up without emptying the digester? A plant in the Northwest which had an eight-to-ten-foot scum blanket in an existing digester, solved the problem by inserting a large-capacity chopper type pump (Vaughan Scum Gun) through a digester manhole. Several precautions were necessary in this operation.

1. Safety precautions were exercised to prevent explosive situations during the installation.

2. Very rapid breakup of the scum caused a load on the digester because food, which had been tied up in the scum, was released into solution very rapidly. It was necessary to monitor volatile acids and alkalinity frequently, similar to any heavy organic loading.

3. Floating covers must be balanced to counter loads caused by placement of the pump. This is particularly important if the pump is placed off center.

MIXING

Use Motor Amperage Readings to Indicate Impeller Wear

A plant in Washington noted progressively worse mixing results in a digester with a draft tube. This unit had a reversible propeller mounted on it. When the unit was pulled for inspection, the propeller which was originally 20 inches in diameter, had been worn to a 10-inch diameter. Amperage readings were compared and it was noted that the amperage had been getting progressively lower because a smaller volume of sludge was being moved. Regular monitoring of the motor's amperage would have warned the operator about this problem.

LINE PLUGGING

How to Unplug a Supernatant Line

Continuous plugging of supernatant lines by scum can be a serious problem, particularly in a fixed cover digester. In one plant, a one-inch pipe was passed through a rubber plug. The plug was fit tightly into the supernatant line and high-pressure water discharged through the pipeline into the digester, dislodging scum.

Freezing a Sludge Line to Install a Valve

During the remodeling construction at one plant, it was necessary to break into a live drain line that had no valve in it. This was done by constructing a two-piece collar to fit around the pipe. The collar was approximately four feet long and four inches larger in diameter than the sludge line. A space was left around the entire diameter of the pipe and the length of the device. Liquid nitrogen was fed into the space in the collar. This method froze the sludge in the pipeline in about two hours, blocking the line. The valve was inserted in the line below the frozen section. About eight hours later the frozen sludge had thawed and began to flow through the newly installed valve.

TOXICITY

For over a year a plant had had chronic problems in starting the digester. The cause of the problem was found to be outside the plant. The digester would show signs of a good startup with increasing acid production, but every weekend the digester would quit working and on Mondays the operator would find no digestion taking place. This was repeated week after week.

Because of the regular cycle of the problem, it was thought that some industry might be involved. The operator found that a furniture factory was consistently dumping about 1,500 gallons of paint waste into the sewer every Friday.

The problem was handled when the operator reduced mixing to three hours a day. This allowed the toxic sludge to stay on one side of the tank and not become thoroughly and immediately mixed with the digester contents. The long-term solution for this problem is to enforce the industrial waste ordinance and prevent the paint dumps at the source.

COLD WEATHER PROBLEMS

How to Prevent Freezing of Digester Pressure Relief Valves

Cold weather problems with gas pressure relief valves are common and one operator found the solution by placing a barrel over the relief valve with a light bulb inside it. The bulb produced enough heat to keep the valves from freezing. This type of device should contain an explosionproof cover over the bulb.

Another method of solving freezing problems in digester pressure relief valves is to put a light grease mixed with salt on the mating surfaces. This will prevent freezing. However, it should be cleaned off in the summertime to prevent corrosion.

DIGESTER DRAINING

Solving a Sludge Removal Problem

Plant operators in one plant needed to empty a digester for routine cleaning. An area suitable for sludge storage was found in a lagoon not connected to the digester. Some method was needed to transfer the sludge other than the existing sludge drawoff line.

It was determined that the city personnel could do the job less expensively than a contractor if they had their own pump and used their own personnel. A pump normally used for emptying barnyard manure pits was fitted with an explosionproof motor and hoisted to the top of the digester.

A tripod was arranged over a large manhole opening and the pump lowered into the digester. A discharge hose was attached to an irrigation pipe to carry the sludge to the lagoon.

The pump had a cutter bar underneath the impeller which chopped up thick scum, rags, sticks, etc. When the thick scum was broken up with high pressure water, it flowed quite easily through the pump.

As the sludge level dropped, the pump was lowered to keep it approximately 1½ to 2 feet below the surface of the sludge.

About two digester volumes of water were needed to liquify the sludge enough to pump. A scum layer about three feet thick and a grit layer about four feet deep were removed from a 50-foot diameter digester in ten days.

How to Control Odors Using Hydrogen Peroxide

When it was necessary to drain a digester containing partially digested sludge, odors were a problem. A line was tapped into the sludge draw-off pipeline and hydrogen peroxide solution at 30 percent concentration was added to the sludge. The concentration was about one gallon for every 12,000 gallons of sludge drawn to the beds.

PLANT STARTUP

A plant with two digesters, primary and secondary, found it necessary to empty the primary for repairs. The following startup procedure was used.

Day	Temp. Deg.	pH	Comments
1			Tank being filled with raw sewage.
3	69	6.7	Tank full.
4	75	6.1	Added 10,000 gallons secondary sludge from another plant.
7	82	5.4	Added 250 lbs. of lime.
8	92	5.5	
9	93	5.6	
10	97	5.9	

11	97	5.7	Added 400 lbs. of lime.
12	97	5.7	Added 200 lbs. of lime.
13	98	5.7	Added 200 lbs. of lime.
19	97	5.7	Added 300 lbs. of lime.
20	98	5.8	Added 150 lbs. of lime.
25	98	5.9	Added 1,000 lbs. of lime in last five days.
35	98	6.0	Added 1,000 lbs. of lime in last ten days.
79	98	7.1	Added 2,000 lbs. of lime in last 44 days in 100-lb. or less increments. Also added 2½ gal. defoaming agent about day 60 to prevent foaming.

Sludge was being added at about 4,000 gpd at 3.3 percent solids and 77 percent volatile. At the end of about 80 days, the volatile reduction averaged about 51 percent.

DIGESTER GADGETS

Operators have devised several gadgets that assist in solving problems around their plants. A few examples are listed on the following pages showing what can be done with little expense and some ingenuity.

DIGESTED SLUDGE SAMPLER—This "home-made" sampler is made from materials found around the plant (some, such as the rubber balls, might even be retrieved off bar screens).

The lead can be poured around the inner can using a metal container approximately one inch larger in diameter. The spring support and trip mechanism can be readily fashioned from scrap materials. The spring is weak enough so that it trips without lifting the device.

A tripod with a reel for raising and lowering can be used to allow selecting samples at the desired depths.

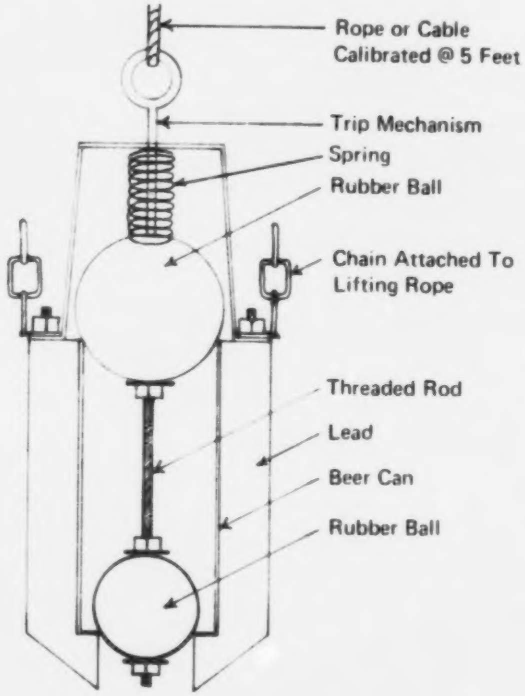

Rope or Cable
Calibrated @ 5 Feet
Trip Mechanism
Spring
Rubber Ball
Chain Attached To
Lifting Rope
Threaded Rod
Lead
Beer Can
Rubber Ball

FIGURE 3-1
DIGESTED SLUDGE SAMPLER

GAS PRODUCTION ESTIMATOR—When the gas meter is not operating, the following system may be used as a rough estimate of gas production.

1. Fill the carboy with sludge from the active zone.
2. Turn on heating pad and hold contents at same temperature as digester.
3. Fill a 500 ml graduated cylinder with water and invert it in a 2 liter beaker over the end of the gas hose, being careful to keep the cylinder filled with water and not admit any air.
4. Allow gas to purge from the carboy for one hour, then set gas tube under lip of cylinder.
5. Note length of time to displace 400-500 ml.
6. Repeat for several consecutive days to get trend of production.

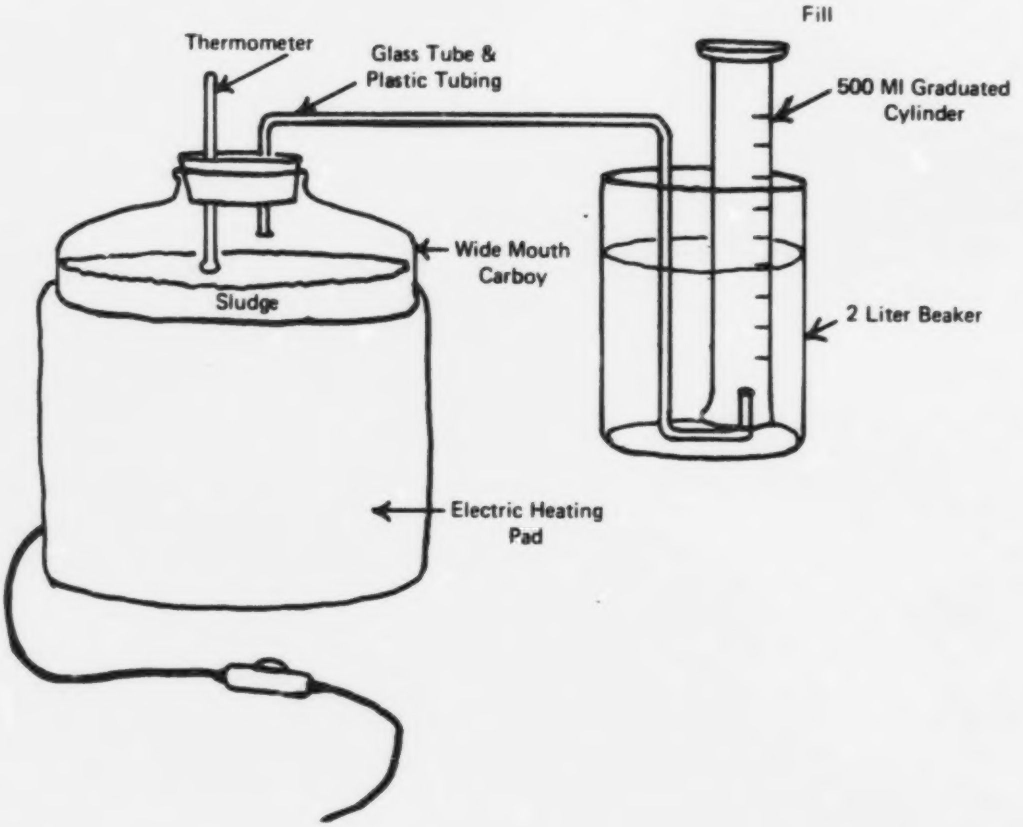

Fill
Thermometer
Glass Tube & Plastic Tubing
500 Ml Graduated Cylinder
Wide Mouth Carboy
Sludge
2 Liter Beaker
Electric Heating Pad

FIGURE 3-2
GAS PRODUCTION ESTIMATOR

SCUM BLANKET FINDER—One method for finding the depth of the scum blanket in a digester is illustrated here.

A one inch pipe marked every foot is attached to a wooden paddle by a hinge. This can be pushed between the digester wall and cover in the first position.

As the finder is raised after passing the bottom of the blanket, the paddle will straighten out and lock under the scum blanket. The appropriate depth mark is noted, the paddle pulled back parallel with the pole and lifted out of the digester.

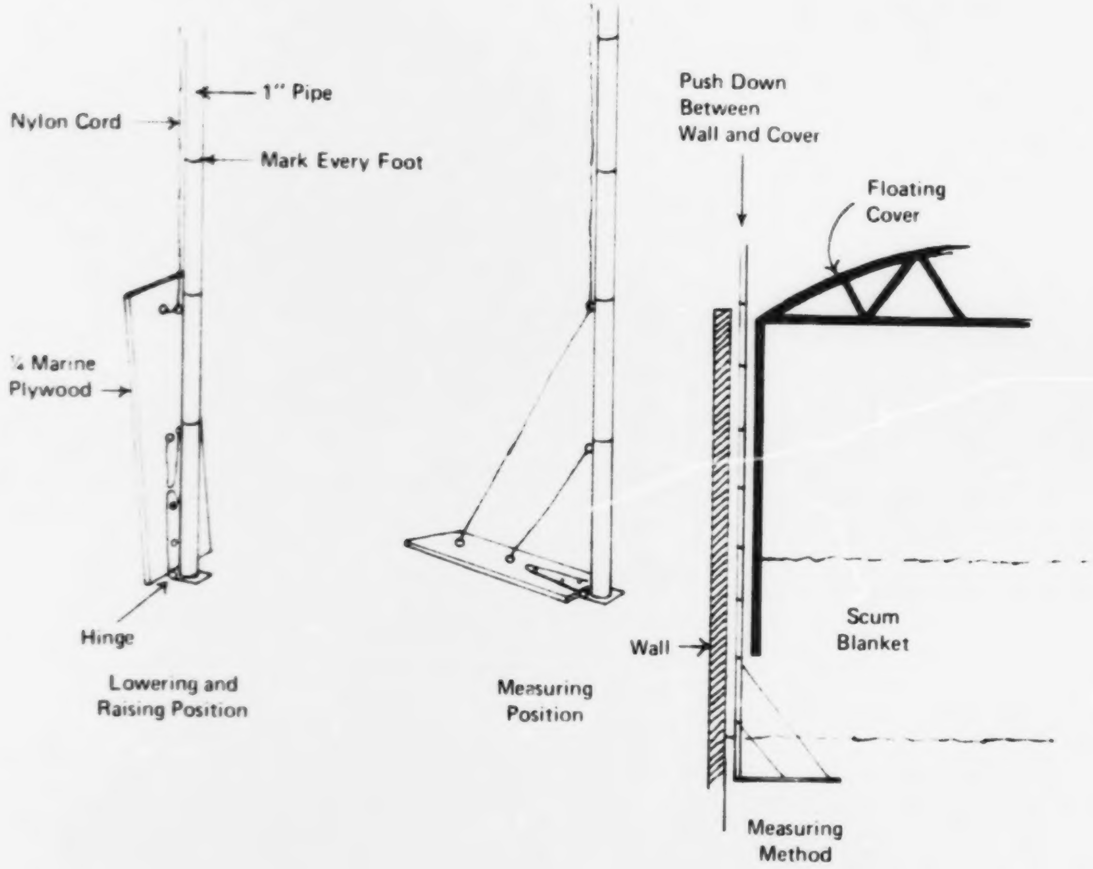

1" Pipe
Nylon Cord
Mark Every Foot
¼ Marine Plywood
Hinge
Lowering and Raising Position
Measuring Position
Push Down Between Wall and Cover
Floating Cover
Scum Blanket
Wall
Measuring Method

FIGURE 3-3
SCUM BLANKET FINDER

SUPERNATANT LINE PURGE DEVICE—Plugged lines due to scum can cause severe problems in fixed cover digesters, particularly in cold weather when pressure relief valves may freeze.

A two inch piece of rubber approximately the same size as the I.D. of the line can be fitted with a piece of pipe through the center and secured for moving up and down in the line.

Either water or steam can be used to loosen the scum.

This may be used also in a chronically plugged sludge line if a tee or wye and valve are provided for access.

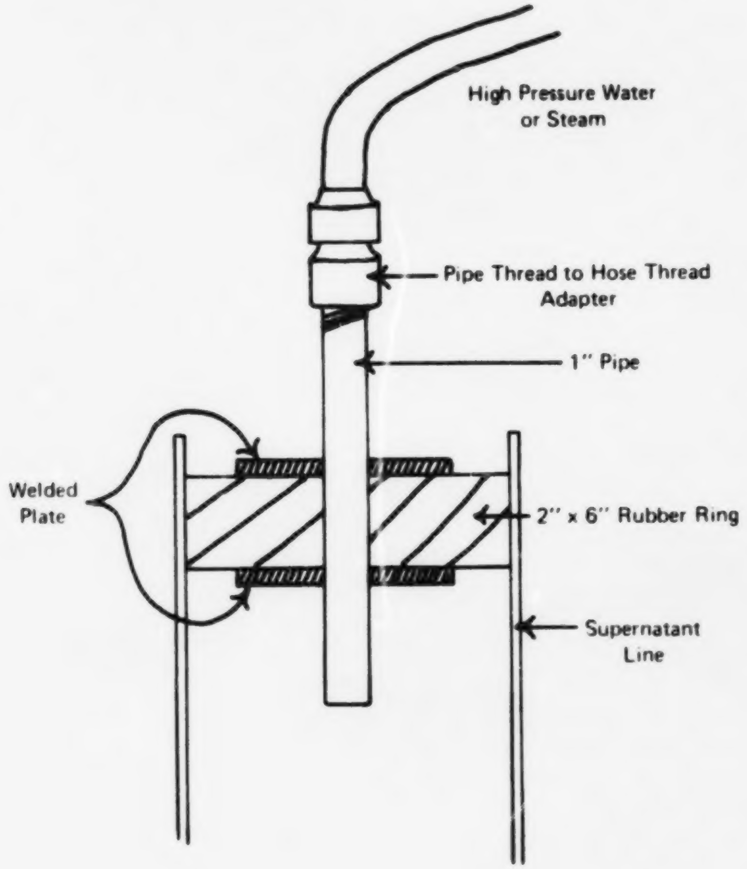

High Pressure Water or Steam
Pipe Thread to Hose Thread Adapter
1" Pipe
Welded Plate
2" x 6" Rubber Ring
Supernatant Line

FIGURE 3-4
SUPERNATANT LINE PURGE DEVICE

AUTOMATIC PUMP SHUT-OFF CONTROL—To prevent damage to the piston pump, sludge piping or valves, a pressure shut-off control can be added to existing systems with a minimum of expense as described below.

An adjustable pressure switch to be used as a permissive interlock in the pump control circuit can be installed. When pressures downstream from the pump exceed the switch setting, the pump shuts off. This effectively prevents damage in the event a downstream valve is unintentionally closed or if plugging develops in the discharge line.

The switch is available off the shelf at electrical or control supply firms.

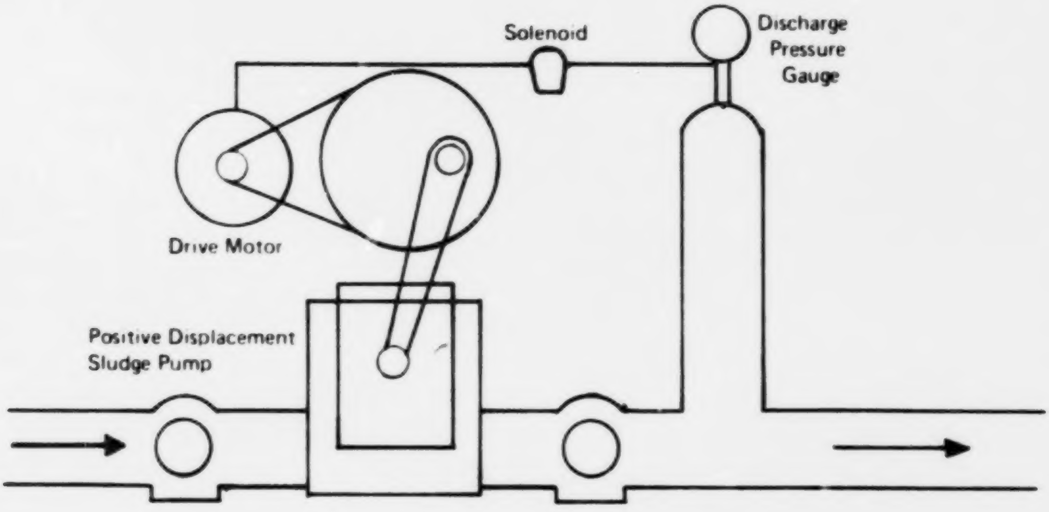

Solenoid
Discharge Pressure Gauge
Drive Motor
Positive Displacement Sludge Pump

FIGURE 3-5
PRESSURE SHUT-OFF SYSTEM TO PREVENT DAMAGE TO PUMP

RAW SLUDGE THICKNESS CONTROL—A rather simple control system was installed at one plant to prevent pumping excess water to the digester by using the amperage from the piston pump motor to sense changing sludge thickness.

Amperage readings were recorded at the same time that total solids samples were collected. It was found that as the total solids decreased, amperage decreased and when the values for the two were plotted on a graph, the minimum desirable solids content could be matched with an amperage reading (see Appendix G for information on graphing).

A load meter that sensed amperage of the motor was installed in conjunction with a one minute time delay switch. When the pump came on automatically, sludge was cleared out of the line, then the load switch sensed the sludge thickness and the pump shut off if the sludge thinned out before the time clock timed out.

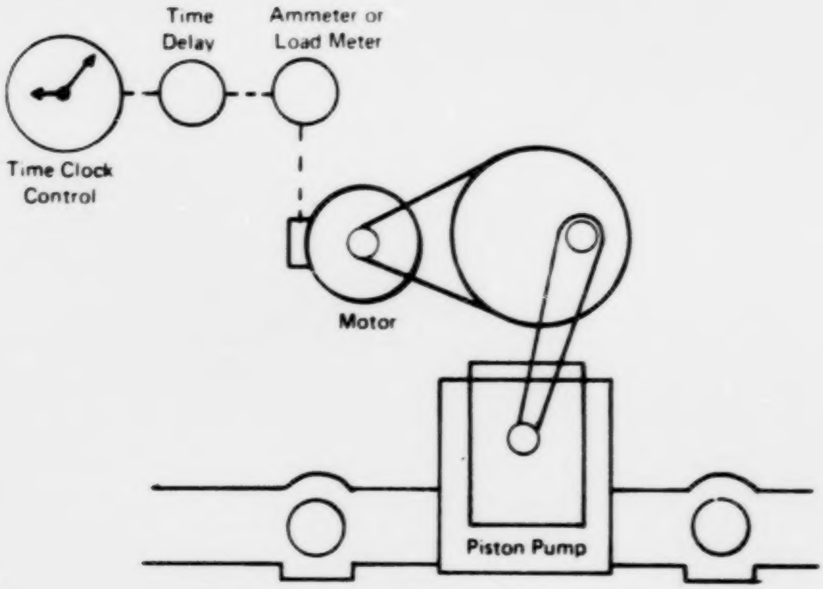


FIGURE 3-6
RAW SLUDGE THICKNESS CONTROL

SUPERNATANT SELECTOR—An "operator made" device was installed in an existing digester while it was down for repairs that helped draw the best possible supernatant even though liquid level varied.

A hoist was mounted on the tank wall and ¼" plastic coated boat control cable was attached to a section of movable supernatant pipe. A swivel joint composed of an ell and street ell allowed the draw off point to be changed by operation of the hoist.

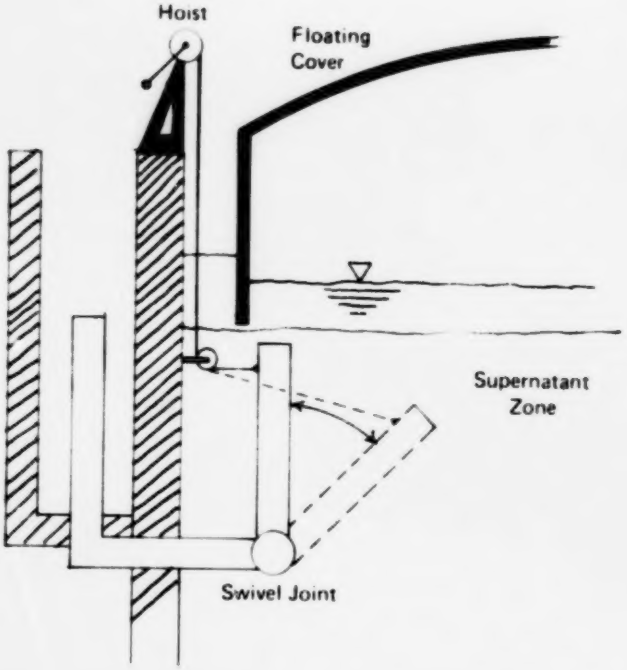


FIGURE 3-7
SUPERNATANT SELECTOR BUILT BY OPERATORS

PART 4

THE BASICS

SUMMARY
INTRODUCTION
WHY DIGEST ORGANIC SOLIDS?
WHAT MATERIALS ARE REMOVED FROM WASTEWATER?
WHAT TYPE OF DIGESTION: AEROBIC OR ANAEROBIC?
WHAT HAPPENS INSIDE AN ANAEROBIC DIGESTER?
WHAT ARE THE PRODUCTS?
HOW IS DIGESTION AFFECTED BY TYPES OF DIGESTERS?
WHAT FACTORS AFFECT SLUDGE DIGESTION?
DIGESTER CONTROL
TYPES OF EQUIPMENT

SUMMARY

Decomposition of organic material in digesters is a continuous two-step process. Two different kinds of bacteria are involved. In the first step, the organic material is converted into organic acids by acid-forming bacteria. The organic acids are used as food in the second step by strictly anaerobic methane-forming bacteria which convert the acids into methane and carbon dioxide gases. During the last step, complete digestion takes place, bound water is released, and the sludge is completely stabilized and ready for dewatering.

The products formed as a result of digestion are a well stabilized sludge, carbon dioxide, methane, and water.

Five factors must be in balance to accomplish digestion: bacteria, food, loading, mixing, and environment. The operator must control all of these factors.

- The bacteria (good seed sludge) must be kept in plentiful supply.
- The food (incoming sludge) should be as concentrated as possible (4 to 8 percent solids), and fed continuously or in frequent small amounts.
- Mixing should be continuous or nearly so to provide contact of bacteria with the food.
- Sufficient time must be provided to permit complete digestion. Digesters must be kept operating at or near full volumetric capacity.
- The environment must be kept within extremely narrow ranges. The optimum conditions are:

Anaerobic Conditions	No oxygen (air)
Temperature	85-95 deg. F
pH	6.8-7.2
No Toxic Material	

The type of digester will affect what the operator can or cannot do to control the process. The degree of layering, scum formation, and supernatant clarity are all affected by type of digester and associated equipment.

Sampling, testing and analysis are the basic steps in making a good digester control program. The purpose of a laboratory testing program is to identify and characterize the kind of waste being sampled. This means that a sample is collected and checked by chemical procedures to find what is in it and how it will act in the digester.

The best and closest digester control is achieved by monitoring the process with more than one control parameter. The tightest control is obtained by monitoring the **ratio** between volatile acids and alkalinity. This method is the one which allows preventive control action and is not too difficult to perform. This method is the best type of control for those plants having other processes which are affected by digester operation.

Various indicators of the progress of digestion are used for predicting possible trouble. These are CO_2, pH, gas production, loading, volatile solids reduction and pounds of solids in the system.

ANAEROBIC SLUDGE DIGESTION

INTRODUCTION

Natural decomposition of organic material has occurred for millions of years. This natural decaying process breaks organic material such as leaves and grass, animal waste, dead carcasses, rubbish and refuse of all kinds into simple elements or compounds that return to the soil as nutrients. These materials are broken down biologically by bacteria which come in all types, sizes and shapes. Some live and work in almost any environment, while others are extremely sensitive. Some use any type of organic material as food, while others are very selective. In a manner of speaking, bacteria eat the organic material as food, digest it, and convert it into end products consisting of liquids, gases and stabilized solids.

Bacterial decomposition can occur with or without air (oxygen). The bacteria that need air use it in the same way we do. These are called aerobes, or **aerobic bacteria**. Bacteria that live without oxygen are called **anaerobic** bacteria. Some bacteria can live under either condition and are called **facultative** bacteria.

Man is perhaps the greatest producer of waste materials. Since man is also an inventive animal, he has discovered that one of the best and cheapeast ways of getting rid of his waste is to put these millions upon millions of bacteria to work for him. All man needed to do was collect his waste material in one place, put it in a container, create the right environment, and let nature take its course. Water is used to carry waste materials from hundreds of sources to a central point where these materials can be removed from the water for treatment. A typical wastewater treatment facility has several "container" processes, each designed to remove or treat these wastes.

WHY DIGEST ORGANIC SOLIDS?

The organic solids removed from the wastewater produce offensive odors when they decompose. These sludges also may contain **pathogenic** (disease-causing) organisms harmful to man.

Sludge also contains water held within the sludge particle which makes it difficult to dewater. It is, therefore, necessary to contain and treat these wastes so that:

1. The treated sludge is stabilized, which means that the sludge is decomposed and further bacterial activity is minimal.

2. The offensive odors are eliminated.

3. Many pathogenic bacteria are eliminated.

4. The disposal problem of sludge is minimized by converting a large percentage of sludge to gases and liquid. Gases can be used as fuel.

5. The sludge is easily dewatered and will dry readily. It has value as a soil conditioner when recycled back to the land.

WHAT MATERIALS ARE REMOVED FROM WASTEWATER?

Figure 4-1 shows that the incoming wastewater contains two basic types of material classified as being about 70 percent organic and 30 percent inorganic. The **organic** portion of the sewage is used as food for bacteria, while the **inorganic** portion passes on through the entire treatment process unaffected. Inorganic material includes rock, grit, rags, plastic, metal, etc.

These materials are normally removed in pretreatment units such as bar screens, rock traps, and grit collectors. Material passing through these collectors contains solids too large to be effectively treated. These must be reduced in size by other pretreatment units such as comminutors and barminutors, which shred the material and allow it to pass through the treatment units. All of these units must operate continuously at top efficiency if the subsequent plant processes are to work properly. The material removed from the wastewater in this phase is usually sent to a landfill site.

After pretreatment, the remaining solids are either settleable, suspended or dissolved. **Settleable solids** are those which are heavy enough to settle out when the wastewater flow is slowed down and enough time is allowed for them to settle. These solids are removed in primary clarifiers and are called raw primary sludge.

The remaining solids are either **suspended** in the water or dissolved just as sugar is **dissolved** in coffee. Most of this material passes on to some form of biological treatment process where it is converted to biological solids heavy enough to settle. These solids are removed from the wastewater flow in secondary clarifiers. Figure 4-1 shows that both raw sludge and biological sludge are sent to the anaerobic digester for natural decomposition.

Of the materials reaching a digester, only the organic portion can be decomposed by the bacteria. The inorganic materials are unaffected by biological treatment, however, they can

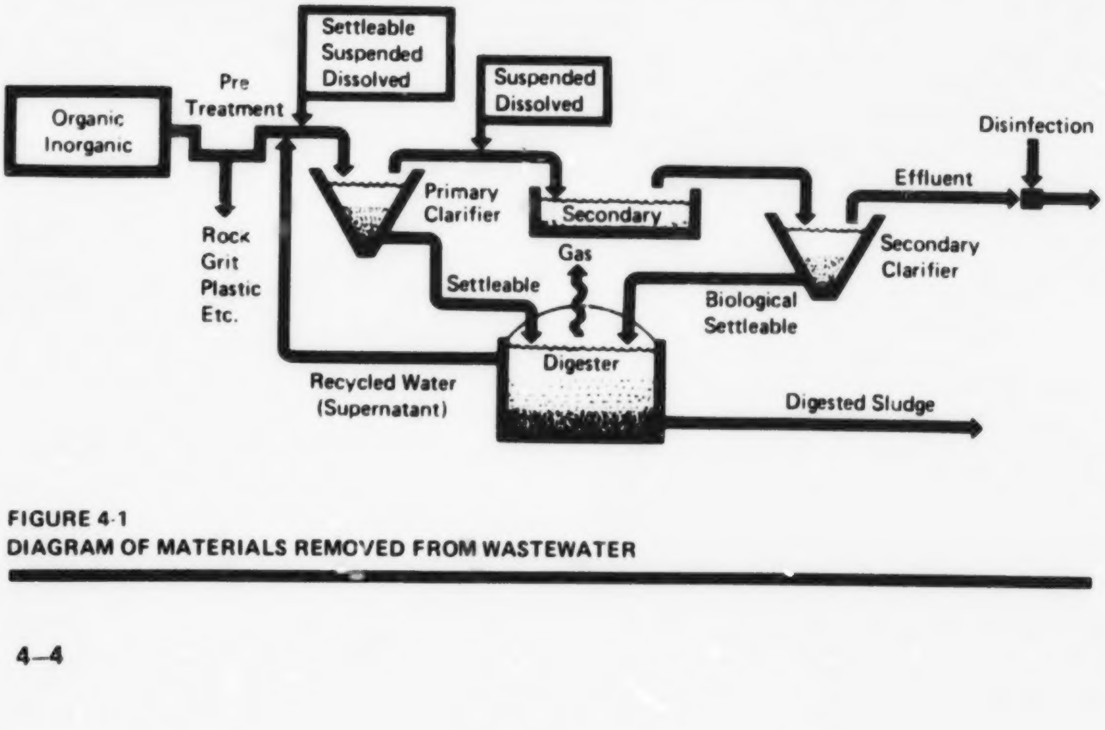

Organic
Inorganic
Pre Treatment
Rock
Grit
Plastic
Etc.
Settleable
Suspended
Dissolved
Primary Clarifier
Suspended
Dissolved
Secondary
Gas
Settleable
Digester
Recycled Water (Supernatant)
Digested Sludge
Biological Settleable
Secondary Clarifier
Effluent
Disinfection

FIGURE 4-1
DIAGRAM OF MATERIALS REMOVED FROM WASTEWATER

cause severe problems, such as reducing digester volume.

Several methods are used to concentrate digester feed sludges. Primary clarifiers, gravity thickeners, flotation thickeners and centrifuges are commonly used.

Primary clarifiers are the only sludge-thickening devices in many plants. Biological sludges, such as activated sludge or trickling filter humus, are often wasted to the primary clarifier and settled with the raw sludge. The sludge concentration developed in the primary clarifier is controlled by the frequency, duration and rate of sludge withdrawal.

Gravity-type thickeners are used in plants which remove raw sludge continuously from the primary clarifier. They yield 4 to 8 percent solids concentration. Waste-activated sludges may be thickened with the raw sludge in these units, but difficulties occur when the waste-activated sludge is young and slow-settling.

Flotation thickeners are often used to thicken waste-activated sludges. These lightweight sludges tend to float, which makes air flotation a practical means to concentrate them to about 3 to 4 percent. The use of centrifuges is another method for thickening waste-activated sludge. Both units will thicken the waste-activated sludge to about 3 to 4 percent.

Regardless of the sludge source, the concentration of total solids fed to a digester should be as thick as possible. Normal ranges are from 3 to 8 percent. This is necessary:

1. To prevent dilution of the **alkaline buffer** which could cause a pH change. NOTE: A buffering material is the amount of alkalinity in the digester needed to offset the acids and keep the pH near neutral.
2. To prevent dilution of the food material. This would make it more difficult for the workers to utilize the food.
3. To reduce the amount of heat required in a heated digester.
4. To provide the maximum **hydraulic loading time** in the digester. NOTE: This is the amount of time in days that the liquid stays in a digester.
5. To prevent washout of solids and organisms.

WHAT TYPE OF DIGESTION: AEROBIC OR ANAEROBIC?

Both types of digestion will do the job when properly loaded and operating in the right environment. The anaerobic digestion process has been used for many years because of its low operating cost, its proven effectiveness on raw primary sludges, and its production of a useful by-product, a burnable gas. This gas has been used as a fuel for boilers, gas engines and heating. But the anaerobic process has some disadvantages. The slow rate of bacterial growth requires long periods of time for starting and limits the flexibility of the process to adjust to changing waste loads, temperatures and other environmental conditions.

The aerobic digestion process has been used successfully to treat waste-activated sludges from secondary treatment plants. These sludges may become a loading problem with anaerobic digesters. The principal disadvantages of aerobic digesters are higher operating costs, high energy demands, and an inability to produce a burnable gas to recover energy.

The remainder of this section will describe the anaerobic digestion process, its operation, and its problems.

WHAT HAPPENS INSIDE AN ANAEROBIC DIGESTER?

Anaerobic sludge digestion is a continuous process. Fresh sewage sludge should be added continuously or at frequent intervals. The water separated from the sludge (**supernatant**) is normally removed as sludge is added. Digested sludge is removed at less frequent intervals but it must be removed. The gas formed during digestion is removed continuously.

The stabilization of organic wastes by anaerobic sludge digestion must always result in the production of methane gas which is insoluble in water and escapes as a gas. Thus, if no methane gas is produced there can be no waste stabilization.

Anaerobic sludge digestion is considered a two-stage process as shown in Figure 4-2. This diagram shows organic material as food is changed in the first stage by **acid-forming bacteria** to simple organic material, chiefly organic acids. The **methane-forming types** of bacteria then use the acids as food and produce carbon dioxide and methane gas. It is important to understand that no waste stabilization occurs in the first stage. Real stabilization occurs only in the second stage.

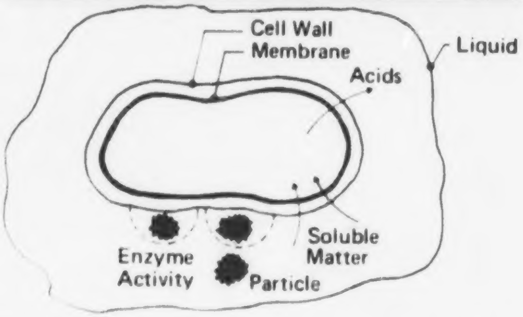


FIGURE 4-3
TYPICAL ACID-FORMING BACTERIA

One of the major considerations is the type of food available to the acid-forming bacteria. Food may be in two forms, soluble and insoluble. In the soluble form it is readily removed (like sugar in water). Insoluble forms, such as fats or complex solids, are more difficult to use. They must first be broken down into a soluble form. This is accomplished, in part, by **enzymes** which are produced by the bacteria. The bacteria can only directly use the soluble solids as food since it must be in this form to pass through the cell wall and the membrane as shown in Figure 4-3. The cell wall acts as a sieve to screen out the large particles, while the membrane selects and guides material both in and out of the inner cell.

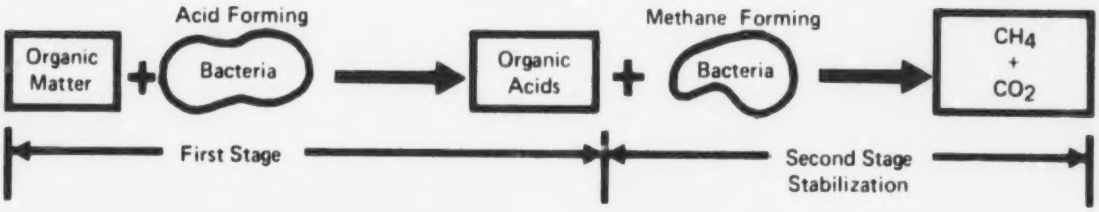


FIGURE 4-2
DIAGRAM OF WASTE STABILIZATION

Not all of the organic solids are completely broken down nor does all of the material pass into the cell. These materials contribute to that portion of digested sludge which is not **degradable** (poor food for bacteria) and that fraction called **inert solids** (not food for bacteria).

The bacteria use the food for energy and produce organic acids also called **volatile acids** or fatty acids. The production of these acids completes the first stage of the digestion process and is commonly known as the acid phase.

In a normal or healthy digester, acids will be used as food by the second group at approximately the same rate as they are produced. The volatile acid content of the digesting sludges usually runs in the range of about 50 milligrams per liter (mg/l) to 300 mg/l, expressed as acetic acid.

If the acid phase was the only step occurring in digestion, the process would be incomplete, resulting in a continuing drop in pH caused by an overproduction of acids. This does occur for a period of time when a digester is first started or when a digester has lost a large amount of its methane formers. *Digestion can only be completed when the second phase is occurring at the same time as the acid phase.*

The second phase in anaerobic digestion occurs because of another bacterial group called the methane formers, which use the volatile acids produced by the acid formers as food. The acids are then converted to carbon dioxide (CO_2) and methane (CH_4) gases as major end products. This step completes the work of the two principal forms of bacteria and results in stabilizing between 40 and 60 percent of the organic waste in domestic sludge.

The methane formers, which are responsible for waste stabilization, grow quite slowly compared to the acid formers since they get very little energy from their food. This causes the methane formers to be very sensitive to slight changes in loading, pH and temperature. Since the methane formers are strictly anaerobic bacteria, they are also extremely sensitive to air (oxygen).

The acid formers have a decided edge over the methane formers since they are rapid growers and are not as sensitive to environmental changes. *Thus, the operation of anaerobic digesters depends largely upon keeping methane formers happy.*

The objective of good digester operation, then, is to control the food supply, the temperature and the pH, thus keeping the acid formers and the methane formers in balance. These subjects are discussed later in this section.

WHAT ARE THE PRODUCTS?

Gases

The major gases produced in any anaerobic condition are methane (CH_4) and carbon dioxide (CO_2). These gases are usually collected, and compressed. The methane portion is used as a fuel gas for boilers, gas engines and other auxiliary uses.

Most of us have seen bubbles rising to the surface of a swamp, especially on a warm day. These bubbles are gases formed by the same kind of methane group as in a digester. Maybe you have noticed that, as the gases rise to the surface, they carry small chunks of bottom sludge and there is a little turbulence in the water—similar to boiling water. The same thing happens inside a digester. In fact, the only mixing in many digesters occurs in this natural manner.

Scum

Scum blankets form in digesters as the result of this upward lift of the gas. The formation of scum presents a special problem to many operators who have unmixed tanks. The scum in these tanks tends to concentrate the food material; the working bacteria are generally concentrated in the bottom sludge. If mixing doesn't bring the two together, there will not be much digestion occurring in the scum layer. In an unmixed tank, the supernatant layer provides a physical barrier between the two.

In unmixed tanks, it is necessary to keep the scum blanket moist so that the gases can get through. However, if the blanket dries, the operator must break it up so that the gases can escape. Methods for breaking up scum blankets are discussed in Part I, Troubleshooting Guide No. 9.

Supernatant

The water or liquid inside the digester comes from two sources: carrier water entering the digester and water formed as solids are broken down. A certain amount of this liquid leaves the digester as supernatant. In most cases, supernatant is displaced as fresh sludge enters the digester. However, in some digesters, it is taken out before sludge feeding.

Supernatant is often normally recycled through the plant and is high in suspended solids and BOD. Many secondary plants have experienced process problems due to the addition of supernatant. The major problems seem to be a buildup of solids in the system and insufficient aeration to accomplish the necessary BOD reduction. Both of these conditions result in a deterioration of the plant's final effluent. One common method practiced by many plants to help correct this problem is to release supernatant frequently and in small amounts to prevent shocking the system. Other suggestions are given in the Operations Section, Part II, page 2-4.

Supernatant quality is affected by the type of digester system, the efficiency of digestion and by the type of waste and its settling capacity. For example, waste-activated sludges tend to thin out the digester contents, resulting in less time for digestion to occur. Mixers tend to homogenize the sludge, making supernatant removal difficult if sufficient settling time is not allowed. ***Good settling conditions are a must.*** The digested sludge must have enough time under quiet, undisturbed conditions to be allowed to settle. This is normally accomplished either by shutting mixers off or by transferring the digested sludge to a second settling tank.

Operators generally use the results from two tests: total solids and volatile solids, to indicate the quality of the supernatant as described later in Digester Control.

Digested Sludge

The inorganic and volatile solids that are not easily digested make up the final product—digested sludge. ***A well digested stabilized sludge must drain easily or be dewaterable and not have a noxious odor.*** The characteristics of the sludge are:

1. Some of the water in the sludge particles is released as the particles are broken down. This makes the sludge easier to dewater.

2. The amount of the well digested sludge leaving the digester is less than the amount of raw sludge entering the digester because the complex organic material has been broken down into simpler substances such as liquid acids, water and gases.

3. The sludge should have a lumpy appearance.

4. The sludge turns black. Light gray streaks indicate a "green" undigested sludge.

5. The original offensive odor changes to a less objectionable odor.

6. Volatile solids in the stabilized sludge should be 40 to 60 percent less than the feed sludge.

Stable (digested) sludge can be disposed of on approved land or landfills after it has been dewatered.

HOW IS DIGESTION AFFECTED BY TYPES OF DIGESTERS?

Single, Unheated and Unmixed Digesters

The simplest digester is a circular or rectangular, unheated, open-top tank, whose contents are mixed naturally by rising gases. This type of digester includes Imhoff tanks and Clarigesters which are two-story units with the top portion serving as a clarifier where the solids settle and then drop through a slot into the lower digester portion. In these unmixed digesters, the sludge arranges itself in layers as illustrated in Figure 4-4.

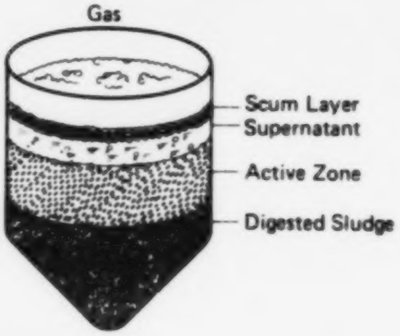


FIGURE 4-4
OPEN-TOP, UNHEATED, UNMIXED DIGESTER

Sludge enters the center of the active zone where digestion takes place and water is released to form a supernatant zone. The decomposed solids are heavier than the liquid and settle to the bottom. As gases are formed, they rise to the surface, pass through the scum layer and escape into the atmosphere. The rising gases carry the lighter sludge particles to the surface above the supernatant and form a dense layer of scum. This scum layer, in time, can become quite thick and be tough enough to walk on.

Figure 4-5 shows the same digester after three to six years of operation.

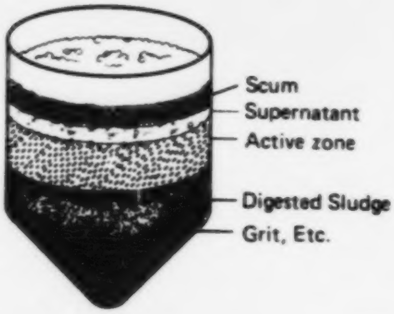


FIGURE 4-5
OPEN-TOP, UNHEATED, UNMIXED DIGESTER AFTER 3 TO 6 YEARS

Deposits of grit and other material on the bottom and a thicker scum layer greatly reduce the effective capacity of the tank. Problems occur more frequently. It may be difficult to obtain a well digested sludge, or the supernatant layer may be hard to find. The unit is easily overloaded and has more frequent upsets.

This type of digester is no longer being built although several remain in use.

Single, Heated-Mixed and Covered Digesters

Now, let's take the same digester, add a cover to collect gas, add a heat exchanger and a pump to pull sludge from the tank bottom, pump it through the heat exchanger and return it to the upper level as shown in Figure 4-6.

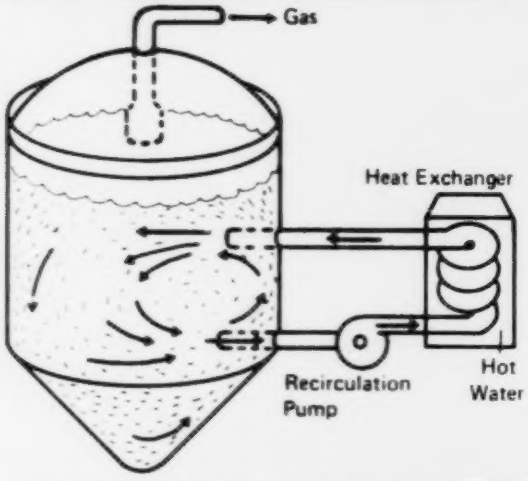


FIGURE 4-6 SINGLE COVERED DIGESTER WITH RECIRCULATION

What changes have occurred? First, the pump is acting like a mixer and sets up a current inside the tank. More bacteria are exposed to the food, and a faster reaction takes place. The heat exchanger raises the temperature of the sludge. The operator can control the temperature to help the bacteria do a better job. In addition, the collected gas can be used as fuel for a hot-water boiler to supply the heat exchanger. Thus, the addition of heating and recirculation equipment reduces the layering effect seen in the unmixed units, complete digestion occurs in less time and a smaller digestion tank can be used.

There are many types of mixers, many ways to heat the sludge, and many ways to collect gases, but they perform the same functions. The major differences are mechanical. These systems are discussed later in this section.

When withdrawing supernatant in these tanks, it is necessary to shut the mixers off and allow the solids to settle before withdrawal begins. The operator should also find the supernatant zone and carefully select the clearest liquid.

Two-Tank Systems

Next are those digestion systems using two tanks: one for active mixing and digestion, and the other serving as a quiet settling tank as shown in Figure 4-7.

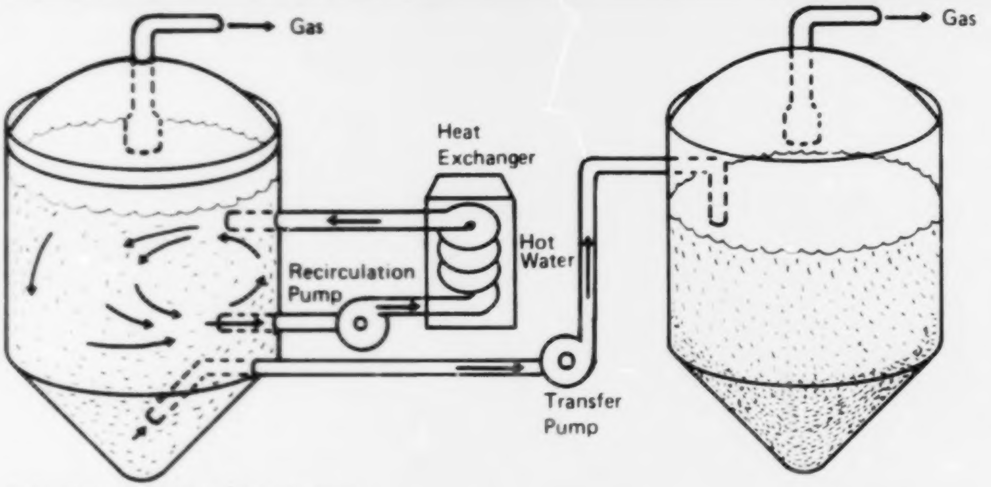


FIGURE 4-7 TWO-TANK SYSTEM

Two-tank systems were designed to shorten the total digester detention time by utilizing one mixed tank (the primary) to provide for active mixing and digestion while the second tank is used to provide settling. These systems are referred to as two-stage digesters.

Operationally, the primary tank can be mixed continuously, since the mixers do not have to be shut off and the contents allowed to settle before withdrawing supernatant or sludge. Generally, more efficient mixing is obtained in these units. Both tanks are covered, and the gas system cross-connected between them. The secondary tank, however, does not produce much gas because most of the gas production occurs in the primary tank.

The secondary tank has another beneficial use. It contains a large volume of good active sludge (bacteria) which can be transferred to the primary when the digestion process is fouled. This seed sludge can be used to correct pH and toxicity problems by using "natural recovery" instead of adding chemicals such as lime.

Conventional Versus High Rate Digesters

The basic difference between these two systems is their loading rates.

Conventional–0.03 to 0.10 lbs. per cubic foot (0.48 to 1.60 kg/m^3) of volatile solids loaded per day.

High Rate–0.10 to 0.40 lbs. per cubic foot (1.60 to 6.40 kg/m^3) of volatile solids loaded per day.

The high rate units achieve their higher loadings because their design includes uniform temperature and greater mixing capacity. The tanks are also usually deeper. Operationally, the high rate system will be fed on a more nearly continuous basis.

WHAT FACTORS AFFECT SLUDGE DIGESTION?

Five basic factors affect digestion: bacteria, food, loading, contact (mixing) and environment. The acid and methane formers can only do their best job as a team when the right conditions are provided. The purpose of this section is to describe the factors needed for good digestion. All of these affect the process and all can be monitored and controlled by the operator.

Bacteria

The digesting and digested sludge contains all of the necessary bacteria to stabilize the sludge. Thus, the operator must keep as much good digested sludge as possible in his digester to have enough workers on hand to do the job. ***Do not remove any more digested sludge than is necessary, but some digested sludge must be removed at regular intervals.*** A good guideline is to have about 20 times as much seed sludge as feed sludge expressed as volatile solids.

In single tank digesters, liquid (supernatant) is displaced as fresh sludge is added. Digested sludge is withdrawn under strict control. In two-tank systems, where the primary tank is mixed, many of the bacteria are trapped in the supernatant from the primary tank and are moved to the secondary tank. The secondary tank contains an abundance of bacteria often called "seed" sludge.

This is good seed material which can be recycled or transferred back to the primary digester. This is a good technique to use when organic overloading or a potential toxic load is expected or has already occurred. This technique is often used by plant operators who favor the "natural process" for recovery. A similar technique can be used for single tanks except that seed sludge would have to be obtained from another installation, hauled to the site and then fed into the digester.

Food

Volatile solids in primary and waste secondary sludges are the food for the bacteria.

Raw primary sludges, compared to biological sludges, produce the clearest and best supernatant and the most easily dewaterable sludge from a digester. When biological sludges are added, good supernatant quality becomes more difficult to obtain. In fact, some plants separately treat biological sludges in aerobic digesters and primary sludge only in the anaerobic digesters to improve total plant performance.

Vegetable fats and oils, such as cooking oils, are readily decomposed in anaerobic digesters, but mineral oils such as fuel oil, automotive oils and greases, and paraffins will cause toxicity problems.

Loading

Feeding is one of the things under the control of an operator. Each operator must consider:

- The **concentration** of the incoming sludge, which is the amount of solids in a given volume of water.
- The amount of **volatile solids** in the incoming sludge, which tells how much of the material can be used as food by the bacteria and indirectly the amount of grit.
- The amount of volatile solids per unit to digester volume, which is used as a **loading factor** in much the same way as the "food to microorganism ratio" is used in activated sludge.
- The **hydraulic loading** (hydraulic detention time) which is related to the organism growth and washout.

These are described in detail beginning on page 4-20.

Contact (Mixing)

Sludge stabilization cannot occur unless the bacteria are brought into* contact *with the food.

The goals are to expose the bacteria to the maximum amount of food and also to reduce the volume occupied by settled inorganic material, such as grit, and organic material, such as scum. The benefits of mixing are speeding up the process of the volatile solids breakdown and increasing the amount of gas production.

This is done two ways:

1. **Gas Evolution.** As gas is produced, it forms in pockets, then breaks loose and rises to the surface. This action creates a boiling effect resulting in some mixing. This method is controlled by feeding. When conditions allow a fairly constant loading, which may be higher than normally designed in conventional digesters, internal mixing will occur. A loading of about 0.4 pounds cubic foot per day is needed for natural mixing. As long as loading can be sustained at this level, no other mixing may be required; however, if prolonged periods of low loading are experienced, mixing may be interrupted and scum blankets may form. On the other hand, increased loading may cause organic overloads with resulting slower gas production. Conditions which cause natural mixing are somewhat unstable but do afford an inexpensive method of mixing if the operation is closely controlled.
2. **By Artificial Means.** Many types of mixing devices are used to stir or mix the digesting sludge. The amount and frequency of mixing are controlled by the operator. These have been described beginning on page 4-27.

Environmental Factors Affecting Digestion

The methane bacteria, which cause the final conversion of digesting sludge into a stable waste, are very sensitive to conditions in the digester. Their activity slows down unless optimum conditions are maintained. The following table summarizes the best conditions for anaerobic digestion.

Table IV-1
OPTIMUM CONDITIONS FOR ANAEROBIC DIGESTION

Anaerobic Conditions	No oxygen (air)
Temperature*	85-100 deg. F (29-37 deg. C.)
pH	6.8-7.2
No Toxic Materials	

** Temperatures between 85-100 degrees F. (29-37 degrees C.) are in the MESOPHILIC RANGE. Temperatures between 120-135 degrees F. (48-57 degrees C.) are in the THERMOPHILIC RANGE. Most digesters operate at mesophilic temperatures.*

The operator must understand the basics of each condition below because they must be controlled to obtain the most efficient treatment.

Anaerobic Conditions. ***No air can be admitted to the digestion tank if anaerobic conditions are to be maintained.*** The methane formers cannot tolerate even small amounts of oxygen. Closed tanks with covers designed to collect the methane gas are used to keep air out. Operators must not allow air into the digesting sludge since an explosive mixture will result when air comes into contact with methane gas. See also Safety section, page 3-6. If air is admitted into a digester, be extremely cautious about possible ignition.

Temperature. ***Temperature controls the activy of the methane bacteria.*** They can function best in the 85-100 degree F. (29-37 degree C.) range or, in another range, 120-135 degrees F. (49-57 degrees C.) Outside these ranges, the bacteria's activity is severely reduced. For example, activity is almost nonexistent at 50 degrees F. (10 degrees C.). It should be noted that, although bacterial actions stop, the bacteria themselves are not harmed but are simply inactive until the temperature increases again.

The methane-formers are affected by changes in temperature of as little as 1 degree Fahrenheit per day, but the acid formers are not as sensitive to temperature changes. Temperature changes greater than 2 degrees Fahrenheit will reduce methane former activity while acids are still forming. This results in losing the buffering capacity and possibly incapacitating the digester. The best bacterial activity will occur in digesters operating at a ***constant temperature*** somewhere between 90 and 98 degrees Fahrenheit (32 and 36 degrees centigrade).

Once the best temperature for the individual digester is found, based on the highest gas production and ability to hold the pH near 7.0, this temperature should be held within 1 degree Fahrenheit. If heating capacity is limited and it is not possible to hold this temperature in winter months, it is better to drop down from 95 degrees F. (35 degrees C.) to 90 degrees F. (32 degrees C.) and hold this value constant than to fluctuate between 92 and 98 degrees F. (33 and 36 degrees C.) over a two- to three-day period in an attempt to reach the higher temperature.

Various statistics are available showing the value, effects and the necessity of heating the digester contents to allow the most efficient use of the process. When the subject of temperature is discussed, the element of time cannot be ignored because solids stabilization can be accomplished at low temperatures if enough time is available. Table IV-2 relates time and temperature to illustrate this point.

These data show that even at 77 degrees F. (25 degrees C.), digestion can occur in about 5½ weeks. However, approximately 60 percent more digester capacity would be

Table IV-2
EFFECT OF TEMPERATURE ON DIGESTION TIME

Temperature (Deg. F.)	Digestion Time (Days)
59	67.8
68	46.6
77	37.5
86	33.3
95	23.7
104	22.7
113	14.4
122	8.9
140	12.6

(NOTE: Deg. C. equals deg. F minus 32 times 0.55)

needed to reach the same efficiency as when the temperature is held at 95 degrees F. (35 degrees C.).

Operation of the heating system will vary with geographical location, size of digester, degree of loading, and in some cases type of industrial waste mixed with the sludge. The following discussion considers some of the important principles of sludge heating.

CONSTANT TEMPERATURE CONTROL. The optimum temperature range for normal digestion is cited at 90-98 degrees F. (32-36 degrees C.). If the digester cannot be heated to 90-98 degrees F. (32-36 degrees C.), it is better to maintain control at a lower temperature (at a constant value) than to fluctuate between high and low temperatures over a short period of time.

CHANGES IN TEMPERATURE. Temperature should not be changed more than 1 degree Fahrenheit per day once the operating temperature has stabilized. During start-up or after recovery from other difficulties which cause the temperature to drop more than 10-15 degrees F. (5-8 degrees C.) the temperature can be brought up to normal at a faster rate, but should be stabilized and held when the normal temperature level is reached. This is particularly true when starting the digester because it may be necessary to raise from 60-95 degrees F. (15-35 degrees C.) in seven or eight days.

THERMOPHILIC TEMPERATURES. Temperatures above approximately 102-110 degrees F. (39-43 degrees C.) cause a change in the major type of methane bacteria and can result in unstable operation if temperatures fluctuate in this region. In the northern part of the nation, where temperature fluctuations affect heating capabilities of the plant, even greater problems will be encountered than in the southern part of the nation. A limited number of plants have operated units for extended periods of time in this range, but the practice is not widespread enough and will not be discussed in detail in this manual. The reader is referred to the City of Los Angeles Hyperion plant article in the WPCF Journal for more information on the subject, as several years of experience have been gained at this plant. See Appendix B, "References."

General methods of sludge heating have been described in this section beginning on page 4-25.

pH. One of the most important environmental requirements is the proper pH. For example, the acid workers can function satisfactorily at any pH level above 5, but the methane workers are inhibited when the pH falls below 6.2. In digester operation, slight decreases in pH will seriously inhibit the activity of the methane workers.

Best Operating Range: 6.8 to 7.2
Tolerable: 6.4 to 7.4

Cases are known where efficient digestion occurs at pH's lower than 6.4, probably due to development of a strain of bacteria able to live in this environment.

The pH of the liquid undergoing anaerobic digestion is controlled by the amount of volatile acids produced and the alkalinity in the digester.

Volatile Acids. The production of organic acids is largely dependent upon the volume of sludge fed to the digester. In a normal or healthy digester, acids will be used as food by the methane formers at about the same rate as they are produced. Under these conditions, the volatile acid content of the digesting sludge usually runs in the range of 50 mg/l to 300 mg/l, expressed as acetic acid.

If the same amount of sludge is fed daily, a population balance between the acid group and the methane group will be maintained easily. On the other hand, if a large amount of readily digestible organic matter were added suddenly, excess amounts of acids would be produced and lower the pH. When this occurs, the methane formers slow down, can't keep up with the acid formers and acids accumulate in the digester.

Buffers in the digester keep the process from becoming upset every time there is overfeeding.

Buffers. Process stability depends largely on a digester's ability to resist a change in pH. This is commonly known as its **buffering capacity** measured as alkalinity. Buffers are essential in digesters. During the digestion process, the methane workers also produce some buffering material, such as bicarbonates, carbonate and ammonia, which goes into solution. The amount of buffer produced in this stage is usually enough to balance the acid produced by the acid workers so that the pH will remain at a constant level.

Alkaline buffers come from two sources:

1. Those already present in the incoming sludge, and
2. Those created as part of the digestion process.

Incoming sludges in communities with hard water supplies or with alkaline wastes from industries have a higher buffering alkalinity, sometimes as high as 6,000 mg/l. These digesters can absorb much higher swings in organic acids before pH is affected. Digesters operating in areas with very little alkalinity in the incoming wastes may need to add a caustic material such as lime, soda ash, or agricultural ammonia to raise the alkalinity.

Changes in the acid production rate or the amount of buffering material can cause changes in pH. Here is what happens when the digester pH suddenly starts to change.

Assume a digester which usually runs at a pH of 6.7 or 6.8 suddenly changes to a pH of 6.5. This means that the natural alkaline buffer in the digester has been reduced, that acids are being made faster than a neutralizing buffer, and that the methane formers can't keep up. First, the operator needs to get the pH back to normal. This gives him time to find the cause of the problem and correct it. pH control continues until the process returns to normal. Typical causes of downward trends in pH are:

1. Sudden changes in organic loading, temperature or type of waste.
2. Lack of pH control.
3. Presence of toxic materials.
4. Slow bacterial growth during start-up.

Volatile acids and alkalinity are measured to indicate the progress of digestion and to control the digester. These test results are normally used as the volatile acids to alkalinity ratio

(VA/Alk) which is the concentration of volatile acids (VA) divided by the alkalinity (Alk). The digester works best if the VA/Alk is less than 0.25, and many operators prefer to keep the VA/Alk less than 0.15 to be safe. This means that there is four to ten times more alkalinity than volatile acids, and the digester will be well buffered to keep the pH from changing.

Toxic Materials. It is important to keep toxic substances out of a digester since they inhibit bacterial activity and can cause complete failure. It is also important for operators to recognize potential toxicity problems and to apply the right corrective measures. All too often, operators have treated a toxic problem as an overload problem and added tons of lime only to find that the problem was still there. Toxic problems and their cures are described in detail in Part III of this manual.

DIGESTER CONTROL

No process can be operated without having adequate control and an indication of its progress. In digester operation, how are controls and indicators defined? ***Controls are short term and used for correction.*** They are tests that can be run to confirm satisfactory operation or to indicate an action that would bring about change. Indicators are tests run, recorded and used for forecasting purposes. Control examples are shown in Figure 4-8.

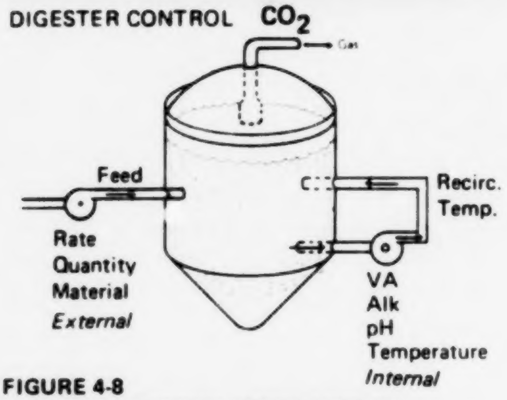


FIGURE 4-8
DIGESTER CONTROL TEST DIAGRAM

External Control

External control tests are used to help the operator control what is coming into the digester. As an example, in normal operation the operator should control the concentration of solids in the feed to avoid diluting the digester contents. To do this, the operator takes a composite sample of the incoming sludge and runs a **total solids** test. This test measures all solids and what percent of the liquid is in solid form. The test and application is described under "Indicators" on page 4-20. Best operation is obtained when the feed sludge concentration is kept as high as possible, preferably in the range of from four to eight percent.

Other external control tests are quantity of sludge handled in pounds per day and tests which describe the characteristics of the incoming sludge. In the latter case, the operator can use this information to tell:

1. Whether the existing grit removal system is operating as well as it should or whether new equipment is needed.
2. Whether toxic materials are present.
3. Whether the sludge is fresh or stale.
4. How much heat will be needed and if the digester operating temperature can be maintained.

Internal Controls

Internal controls, illustrated in Figure 4-8, show what is happening inside the digester. **Four tests are recommended for best control: temperature, volatile acids, alkalinity and pH.**

TEMPERATURE. Temperature directly affects the work of the methane bacteria as explained earlier on page 4-13. **Variations in temperature should never exceed more than one degree per day.** The best temperature range lies between 85 and 100 degrees Fahrenheit (29.37 degrees centigrade). However, the best temperature for any given digester is based on

1. The highest gas production.
2. Ability to hold the volatile acids to alkalinity ratio between 0.1 and 0.25.
3. Maintaining the pH near neutral (6.8 to 7.2)

Thermometer locations vary according to the design of the digester. Some are inserted into the digester wall, or in the sludge recirculation line. Many operators must take temperatures from samples drawn from the supernatant overflow or from thief holes.

VOLATILE ACIDS/ALKALINITY. The major internal control combines two lab tests volatile acids and alkalinity. The alkalinity of a digester is important because it represents the ability of the digester to neutralize the acids formed during digestion or present in the incoming waste. The results of these two tests expressed in mg/l (milligrams per liter) are combined as a ratio (volatile acids divided by alkalinity) and expressed as a single number. For example, 140 mg/l of volatile acids per 2,800 mg/l alkalinity is shown as

$$\frac{140 \text{ mg/l}}{2{,}800 \text{ mg/l}} = 0.05$$

These two tests are run on sludge samples from the primary digester. Typical sampling points are from the recirculated sludge line and from special sampling pipes located at different tank levels. (NOTE It is important to let the sludge in the line run for a few minutes in order to obtain a representative sample.) Other sample points are from flowing supernatant drawoff tubes or thief holes. Do not take a sample immediately after adding sludge to a digester because of possible short circuiting. Mix the contents thoroughly first.

The concentrations of volatile acids and alkalinity are the first measurable changes that take place when the process of digestion is becoming upset. As long as the volatile acids remain low, compared to alkalinity, the digester can be considered healthy with good digestion taking place. The volatile acid/alkalinity relationship can vary from less than 0.1 to about 0.35 without significant changes in digestion. Each plant will have its own characteristic ratio for good digestion. An increase in the ratio is the first warning that trouble is starting in the digester and that serious changes will occur unless the increase is stopped. If the ratio increases, the following changes will occur

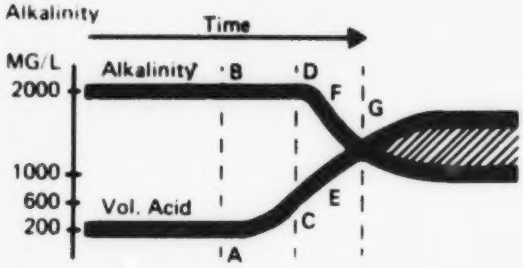
1. The CO_2 content of the gas will increase.
2. The gas production rate will decrease.
3. The pH of the digester will drop and the digester will go sour.

pH. The pH is one of the simple tests that can be run to indicate the progress of digestion and should be run frequently (at least once per operating shift). The danger lies in depending too much on pH as a process control. Because of the alkalinity in the digester, the pH changes very slowly. In fact, the digester may be completely upset before the pH changes.

Frequent monitoring of the volatile acids and the alkalinity and plotting the VA/Alk ratio provides the best information for controlling digesters because these indicators are the first to show a change when the process begins to become upset.

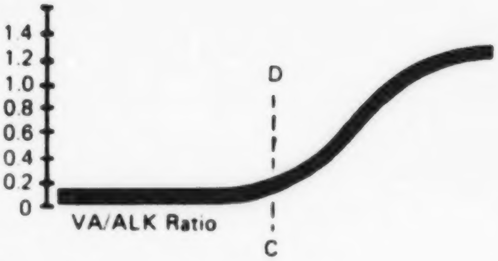
The graphs in Figure 4-9 illustrate the sequence of the change within the digester.

I Relationship Of Volatile Acids To Alkalinity



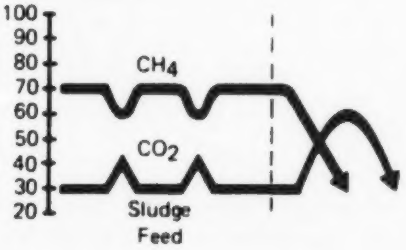
This graph shows a digester operating with a good buffering capacity (the low volatile acids 200 mg/l compared to an alkalinity of 2,000 mg/l. At Point A, something has happened to cause the volatile acids to increase followed by a decrease in alkalinity at Point D. At Point G, the digester has become sour.

II Volatile Acids/ Alkalinity Ratio



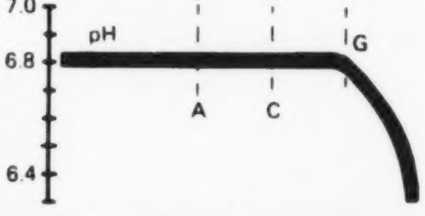
This graph continues the same digester performance by showing the volatile acids/alkalinity ratio. Notice that at Points CD, the increase in volatile acids produces an increase in the ratio from 0.1 to 0.3

III Relationship Of The Change In Ratio Of CO_2 To Methane (CH_4) As A Result Of "I"



By comparing this graph with Graph II, methane production begins to drop with a corresponding increase in CO_2 when the ratio in Graph II reaches about 0.5.

IV Relationship Of pH Change To Change In "I"



pH doesn't change in this graph until the digester is becoming sour at Point G.

FIGURE 4-9 GRAPH OF CHANGE SEQUENCE IN A DIGESTER

Digesters respond slowly once they are upset. Therefore, the best operation is obtained by **preventing upsets**. The following general guidelines are given for best process control.

1. Routine volatile acids and alkalinity determinations during any startup process are a must in bringing a digester to a state of satisfactory digestion.

2. Measure the volatile acid/alkalinity ratio at least twice per week during normal operation, plot against time and watch for trends. NOTE: An example of this is found in Appendix G.

3. Measure the volatile acid/alkalinity ratio at least daily when a digester is approaching trouble such as an increased solids load from waste discharges or a storm.

4. CO_2 and pH tests may be substituted for volatile acids/alkalinity control in those cases where the loading is uniform and predictable and process upsets are infrequent. It is important, however, to realize that failures are costly in terms of both money and time.

The following suggestions are given for corrective response when the volatile acids/alkalinity ratio exceeds 0.35.

1. Extend the mixing time of digester contents.

2. Control heat more evenly.

3. Decrease sludge withdrawal rates.

4. Pump some seed sludge from the secondary digester to the primary using the following guidelines.

   a. Draw down the primary digester to make room for the sludge addition.

   b. Use the volatile acid/alkalinity ratio as a guide to determine how much seed sludge should be added. Hold the ratio to less than 0.25.

Several methods are available for performing the volatile acids test.

1. **Silicic Acid or Chromatographic Method.** This is the preferred method when high accuracy is required. The test can identify up to 95 percent of the organic acids present in the sample. It is the only test recommended by ***Standard Methods for the Examination of Wastewater***. The test requires about one hour to run. The disadvantages include the need for more special equipment and more chemicals than the other methods.
   Appendix E.
   Standard Methods, 13th Edition, page 577

2. **Straight Distillation Method.** This is one of the most commonly used tests since the procedure is fairly straightforward and does not require any special equipment. The test is not for accurate work but is satisfactory for digester control. The disadvantages are the test's dependency on lab techniques to obtain good results and it requires about an hour to run.
   Appendix E.
   Washington State Wastewater Plant Operator's Manual

3. **Titration or Nonstandard Method.** This test was originally developed by R. DiLallo and O.E. Albertson and is listed in the WPCF Manual of Practice. The test takes about ten minutes to run and is reported good when volatile acids exceed 250 mg/l.
   Appendix E.
   MOP No. 18, ***Simplified Laboratory Procedures for Wastewater Examination***
   WPCF Journal, Volume 33, April 1961, page 356

Process Indicators

Process indicators are those tests used for forecasting purposes rather than control. Test results are always recorded and best use is made when they are graphed. Procedures for graphing are described in Appendix C. The most common tests used are shown on Figure 4-10 and described below.

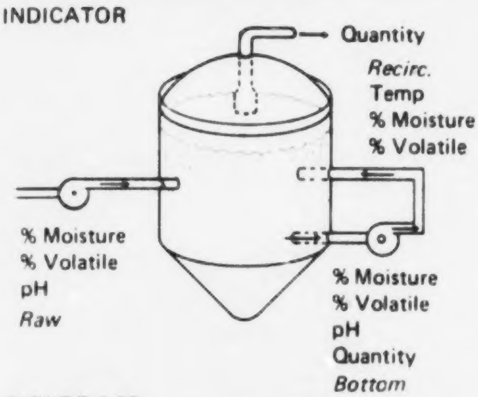


FIGURE 4-10
DIGESTER INDICATOR TEST DIAGRAM

Solids. Several points in the digestion process are sampled and tested for solids—both **total solids** and **volatile solids**. These points are raw sludge feed, recirculated sludge, supernatant and digested sludge.

These tests are needed to gain information on such things as concentration, loading rate, pounds of solids handled through the process and the percent reduction of volatile solids.

TOTAL SOLIDS. Sludge concentration is determined by drawing a sample from a well mixed point for each source, such as raw sludge feed, digester mixed sludge and supernatant, and then performing a **total solids** test. Total solids is obtained by evaporating all of the water from a weighed sample and weighing the residue. The results are expressed in percent of solids (dry basis). The percent of solids can be converted to mg/l as follows:

water from a weighed sample and weighing the residue. The results are expressed in percent of solids (dry basis). The percent of solids can be converted to mg/l as follows:

10,000 mg/l equals 1 percent solids
20,000 mg/l equals 2 percent solids
and so on . . .
5,000 mg/l equals 0.5 percent solids

94% WATER
6% SOLIDS

To convert mg/l per million gallons into pounds:

mg/l times volume in million gallons times 8.34 equals pounds (OR)
mg/l x MG x 8.34 = lbs.

The effect of sludge concentration on digestion time can be seen in the following example. Suppose an operator pumps 12,800 gallons (48400 l) of raw sludge with 2 percent (0.02) solids and then changes the method of pumping sludge to increase the concentration to 4 percent (0.04). The reduced amount to be pumped can be found by setting up the following ratio:

$$\frac{0.02}{12{,}800 \text{ gals.}} = \frac{0.04}{X \text{ gals.}} \text{ then}$$

$$\frac{0.02}{0.04} \times 12{,}800 = 6400 \text{ gpd } (24000 \text{ l/day})$$

The same amount of food would be added. For example:

1. 0.02 x 12,800 gpd x 8.34 lbs./gal.
   = 2,135 lbs./day (968 kg/day)

2. 0.04 x 6400 gpd x 8.34 lbs./gal.
   = 2,135 lbs./day (968 kg/day)

VOLATILE SOLIDS. ***Volatile solids tests are used to indicate* organic loading *to the digester and* digester efficiency**.

Digester operators need to know what percent of the total solids entering the digester is coming in as food matter to be decomposed by the bacteria. This is found by a volatile solids test. The residue from the total solids test sample is burned at 550 degrees centigrade until a white ash remains in a dish. The ash is then weighed, and this weight is subtracted from the total solids weight. The difference between the two weights represents the volatile or organic portion and the residue after burning represents the ash or the inorganic portion. This is shown in Figure 4-11.

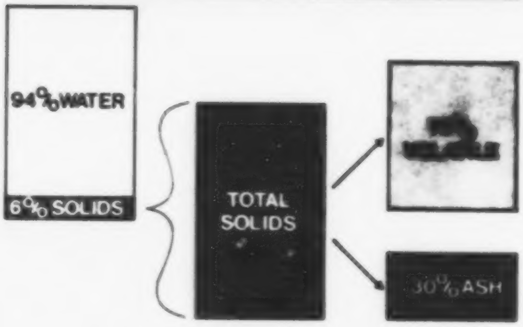


FIGURE 4-11 SLUDGE FEED DIAGRAM

Volatile solids is usually expressed as a **percent of total solids**. The numbers in these examples were used only to illustrate relative proportions and may be different than actual plant conditions.

Let's carry the example one more step and find out what typically happens to the sludge fed to a digester as shown in Figure 4-12.

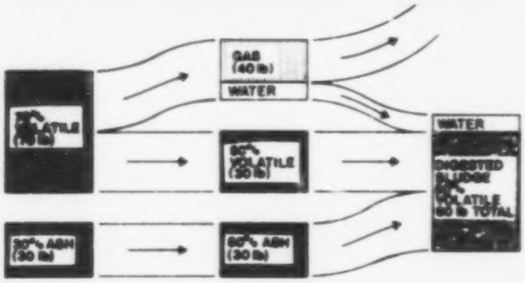


FIGURE 4-12
HOW VOLATILE SOLIDS ARE CONVERTED
TO STABILIZED SLUDGE

For example, assume 100 pounds (45.4 kg) of total solids coming into a digester. Then 70 pounds (31.8 kg) of this material is volatile solids and 30 pounds (13.6 kg) is ash or inert material. As the volatile solids portion undergoes digestion, it is converted into 40 pounds (18.1 kg) of gas and water and 30 pounds (13.6 kg) remain as undigested volatile solids. Notice that the ash portion has been unaffected by digestion and remains as 30 pounds (13.6 kg).

It is desirable to feed the digester with the highest volatile solids content sludge possible. This is done with an efficient grit removal system. The volatile content is an indirect way of measuring the amount of grit material in the incoming sludge as well as directly measuring the amount of food available to the bacteria. It has been found that the volatile content of incoming sludges should be above 70 percent. This means that the plant's grit removal facilities must always operate at top efficiency to prevent filling a digester with grit and reducing its capacity. Figure 4-5, on page **4-9**, illustrates an inefficient digester condition resulting from grit accumulation. Typical grit removal equipment includes grit channels, detritus tank and cyclonic grit separators.

Now that we've discussed solids and what happens to them in a digester, let's look at loading and efficiency.

Two different loading factors, organic load and hydraulic load, are important process indicators.

ORGANIC LOADING. Organic load is the amount of food (volatile solids) fed to the digester each day and is normally calculated as pounds of volatile solids fed per day per cubic foot of active digester volume.

The method most commonly used to express loading is to relate the amount of volatile solids in the feed sludge to the active volume in the digester. This figure is calculated by: (1) averaging the volatile solids content of the raw sludge, (2) knowing the total pounds of sludge pumped into the digester in a given period, (3) measuring or calculating the volume of the digester, (4) dividing the digester volume into pounds of volatile solids.

$$\frac{\text{lbs. raw sludge/day} \times \text{\% volatile content}}{\text{available digester volume}}$$

The number that results can be expressed as pounds of volatiles per cubic foot of digester capacity, or as pounds of volatile solids per 100 or per 1,000 cubic feet (2.83-28.3 m^3) of capacity. This number is similar to the expression used in activated sludge known as the F/M ratio, except that this is an expression of the amount of food to the volume of the digester.

The amount of active volume before digestion takes place is affected by both the amount of scum that is on the surface of the tank and the amount of grit and inorganic material on the bottom. When the tank starts out in a clean condition, the active volume is essentially equivalent to the total volume of the tank. As time progresses, this active zone is reduced more and more, causing a higher loading ratio. Looking at it another way, less volume is available to treat the same or an increased amount of solids compared with what was available originally.

The following example will help to illustrate changes in loading. The volume when a digester is first put into operation is compared with the volume four years later without cleaning the tank.

Needed information:

Digester volume (**available volume**)
Pounds of raw sludge feed
Volatile content

Example:

Assume the available volume of a new 50-foot diameter (15.2 m) digester is 50,000 cubic feet (1416 m^3), raw sludge is 8,000 (3630 kg) pounds per day, volatile content is 74 percent.

Then:

8,000 pounds/day × 0.74
= 5,920 lbs. (2687 kg) VS per day

Loading:

$$\frac{\text{5,920 pounds/day}}{\text{50,000 cu.ft.}} = \text{0.11 lbs. VS}$$

per cu. ft. per day (1.76 kg/m^3/day)

Let's continue the example to see what changes have occurred to the same digester four years later with the same loading rate. The operator measures the scum blanket and grit layer (as described in Part III, page 3-31), and finds the scum averaging 5 feet (1.5 m) deep and the grit 3 feet (0.9 m) deep. The available volume has been reduced by a total of 8 feet (2.43 m) which represents a loss of

$$\frac{\text{8 ft.} \times \pi \times \text{dia.}^2}{4} = \frac{8 \times 3.14 \times (50)^2}{4}$$

$$= \text{15,700 cu. ft. (445 } m^3\text{)}$$

Loading now is

$$\frac{\text{5,920 lbs./day}}{\text{(50,000} - \text{15,700 cu.ft.)}}$$

$$= \text{0.17 lbs. VS/cu.ft./day}$$
$$(2.72\ kg/m^3/\text{day})$$

This change in loading from 0.11 to 0.17 pounds of VS per cubic foot per day (1.76 to 2.72 kg/m^3/day) will make the digester harder to operate and may cause more frequent upsets.

HYDRAULIC LOADING. ***The hydraulic loading is the average time in days that the liquid stays in the digester and is related to digester capacity.*** Hydraulic loading is calculated as follows:

Hydraulic loading equals
Digester Volume/Feed Volume

For example, at an average pumping rate of 12,800 gallons per day into a 250,000-gallon digester, the detention time would be:

$$\frac{250{,}000 \text{ gallons}}{12{,}800 \text{ gal./day}} = 19.5 \text{ days}$$

There is a minimum time required by a digester to convert the solids into an acceptable sludge. The minimum hydraulic loading varies with the type of digester and the type of solids (up to six months for a single unheated unit to as low as ten days for a high-rate system).

If the time is too short, the methane formers will not have enough time to convert the acids produced by the acid formers to methane gas. Some wastes need a longer time. For example, a purely domestic waste needs a fairly short time to complete the decomposition of solids, but the same kind of municipal waste with cellulose added by an industry would need a much longer period.

Treatment plants located in agricultural communities where food processors operate on a seasonal basis have other problems because the amount of sludge produced suddenly increases when the food processing plant starts up. The increased volume of sludge produces an immediate overload on the digester. The operator must watch the digester and add lime or other caustic to keep the buffering capacity high. Often the good sludge in a secondary digester is used to accomplish the same purpose.

The hydraulic loading time can be increased by prethickening the feed to reduce the amount of water fed. Too much water in the feed causes a hydraulic washout of both feed and organisms.

QUANTITY OF RAW SLUDGE. Amounts of raw sludge pumped may be found by several means, but should be recorded even if it is an educated guess as to the amount. The amount may be measured by reading a magnetic flow meter output, by measuring the volume of a piston pump barrel and counting the number of strokes per minute, by calculating the volume of a sump or pit from which sludge is pumped and recording the number of pits full or sumps full pumped in a day, or by measuring the distance traveled by a floating cover on a primary digester. One or more of these methods may be available to the operator; even an educated guess as to amount is better than no information at all.

When more than one means exists for making this determination, it is a good idea to compare two different methods. For instance, if measurements are made by estimating the amount pumped out of a pit and into a digester with floating cover, estimate the volume of each and compare results over several days to see how close they are.

DIGESTER EFFICIENCY. The "In-Out" test using volatile solids indicates digester efficiency. Normally samples are drawn from the digester feed sludge and from the digested or bottom sludge. However, the active digester sludge can be substituted for the bottom sludge.

Digester efficiency can be calculated using the volatile solids test results in the following formula:

$$P = \frac{(\text{In} - \text{Out})}{\text{In} - (\text{In} \times \text{Out})} \times 100\%$$

Where **In** represents the percent of volatile solids entering the digester and **Out** represents the percent of volatile solids leaving the digester and **P** is the percent reduction of volatile solids.

Example

Assume that the volatile solids entering a digester is 70 percent and that a test showed 50 percent volatile solids leaving the digester.

In = 70% = 0.70

Out = 50% = 0.50;

Then,

$$P = \frac{(.70 - .50)}{.70 - (.70 \times .50)}$$

$$\times 100\% = \frac{.20}{.70 - .35}$$

$$\times 100\% = \frac{.20}{.35} \times 100\%$$

$$P = .57 \times 100\% = 57\%$$

The In-Out tests can be used for indication purposes. For example, if the trend shows a decrease in percent reduction, then, this might mean that the:

1. Volume of the digester has decreased.
2. Throughput has increased.
3. Temperature is not high enough.
4. An inhibitory or toxic material has entered the digester.

CO_2. This is a most easily measured major component in the digester gas. Because the sum of the CO_2 and CH_4 (methane) is approximately 100 percent, the amount of CH_4 can be roughly estimated by measuring the CO_2. The CO_2 content of the gas in well operating digesters ranges from 25 to 35 percent. ***The percent of CO_2 can be an early indicator of problems.*** When the percent of CO_2 begins increasing, trouble may be on the way. It is important, however, to realize that the percent of CO_2 will increase soon after feeding if sludge is fed into the digester intermittently. If sludge is fed to the digester only two or three times a day, information should be obtained at different times during the day to find normal values for the plant. The best procedure for taking the CO_2 test is to take it the same time after feeding.

Gas Production. ***Gas production from a digester should be fairly constant if the feed is constant.*** Gas production should range between 7 and 12 cubic feet for each pound of volatile matter destroyed.

pH. ***pH run on raw feed may indicate the presence of toxic material and whether the incoming sludge is septic or fresh.*** Tests on the digester contents indicate the balance of neutralizing buffer. Changes show the need for making caustic additions. The normal range for pH in digesting sludge is from 6.8 to 7.2.

Summary: Process Control Indicators. As a summary, some early indications of problems are given by graphing the following parameters: pH, CO_2, alkalinity and volatile acid ratio and gas production. Direction of the parameter compared to time is more important than absolute numbers. Table IV-3 below illustrates how direction of several of these parameters can indicate possible problems.

Table IV-3
DIRECTION OF PROCESS INDICATORS OCCURRING SIMULTANEOUSLY INDICATE POSSIBLE DIGESTER PROBLEMS

Indicator		pH	CH_4	CO_2	Alk.	Vol. Acid
	Trend of graph					
pH	down		down			
CH_4 (amount)	down	down		up	down	up
CO_2 (percent)	up		down			
Alk	down	down				
Vol. Acid	up		down			

TYPES OF EQUIPMENT

Sludge Heating

Submerged Burners. There are two general types of these devices, one of which discharges hot gas and flame directly into the sludge (see Figure 4-13). The other type has a burner that is enclosed in a ductwork tubing arrangement which allows the flame to heat the interior of the tube, while the tube passes through the contents of the digester. Hot gases are exhausted through an opening in the roof (see Figure 4-14).

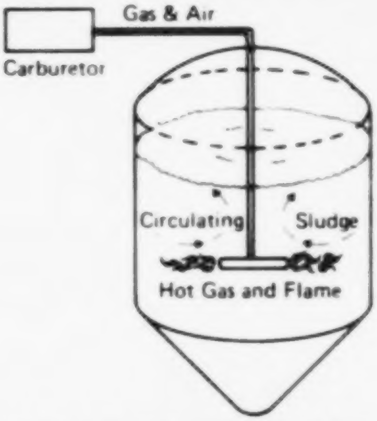


FIGURE 4-13 INTERNAL SUBMERGED BURNER

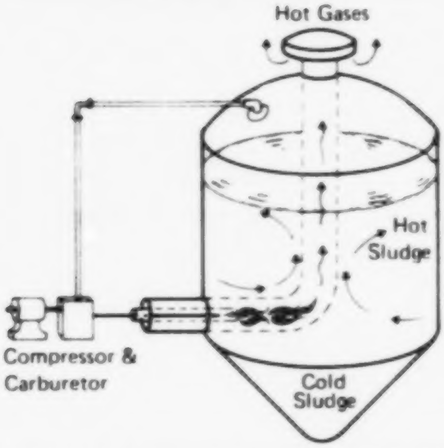


FIGURE 4-14 EXTERNAL SUBMERGED BURNER

Steam Injection Into the Digester. Digester gas or other fuel is used to fire boilers which supply steam to be injected into the digester. Generally, multiple steam feed points are used--either as pipes that extend to some point below the sludge surface or are connected into sludge feed lines. Several companies make steam injection devices that are mounted in the sludge pipeline downstream of any valves.

This type of system adds water to the tank contents and, because boilers must be continuously fed, boiler water conditioning is an important operational consideration.

Equipment that is standard with steam injection systems includes:

1. Boiler water conditioning.
2. Steam lines which require safety precautions.
3. Check valves which prevent sludge backing up in the lines.
4. Pressure gauges and steam line controls.

Particular care must be taken that check valves function correctly in lines that connect with sludge under pressure. A check valve failure in one plant with this type of heating system caused sludge to be transferred into the boiler. Fortunately, the boiler was not hot at the time of the discharge or a serious explosion could have occurred. After this accident occurred a second check valve was placed in the line backing up the first one as an added safety measure.

Steam Injection Into Preheat Tank. A system similar to that described for "Steam Injection Into The Digester" allows raw sludge to be heated in a separate tank before being pumped to the digester. Steam is injected into the tank until a preset temperature is reached.

Digester sludge may also be recirculated through the tank, or both raw and digested sludge may be introduced simultaneously

Hot Water Transferred to Internal Digester Heat Exchanger. Hot water from gas fired boilers or cooling water from gas-driven engines may be pumped through several different types of devices located inside the digester. Each type is described below.

1. Coils of pipe placed inside the tank and normally secured to the wall allow hot water to circulate around the walls and return to the heat source. Various types of mixers cause the sludge to move past the hot water pipes. In some older installations, natural convection currents caused by rising hot sludge may provide the only mixing available (see Figure 4-15)

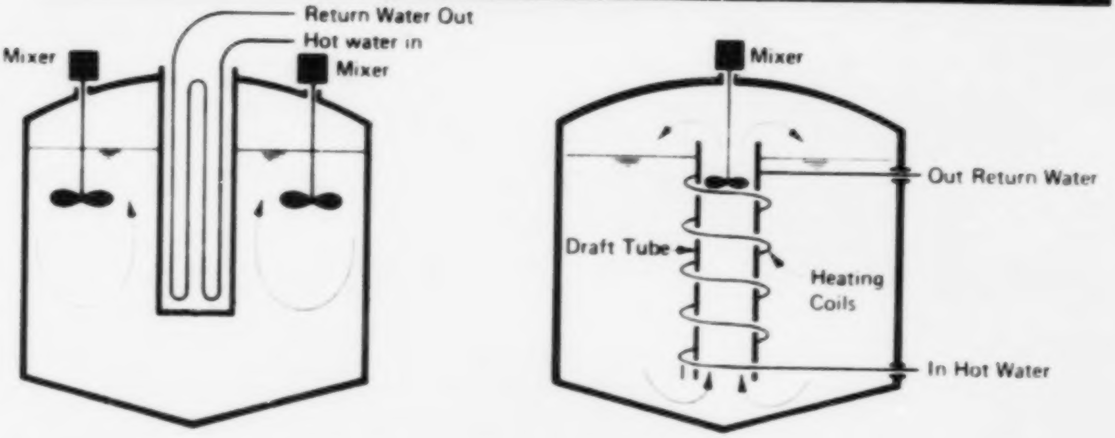


FIGURE 4-16 INTERNAL HEAT EXCHANGERS

2. Several different systems with heat exchangers surrounding draft tubes are used. The principle is to move sludge to pass heated surfaces to increase heat transfer (see Figure 4-16).

Common equipment is listed as follows

1. Hot water source (boiler or engine jacket).
2. Heat exchanger circulation pump.
3. Heat exchanger submerged in tank.
4. Expansion tank.

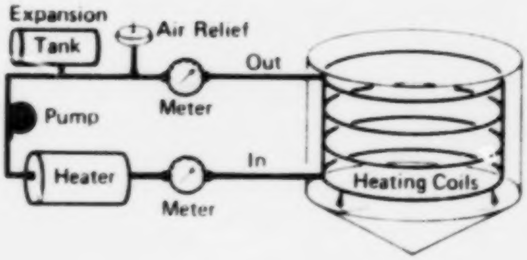


FIGURE 4-15 INTERNAL HEAT EXCHANGER

5. Water meters.
6. Air relief valve.
7. Temperature gauges for monitoring the water and sludge systems.
8. Temperature gauges for controlling the heater and circulation pump.

External Heat Exchanger. Many of the major pieces of equipment are the same as those discussed for internal heat exchangers. In this system, sludge is circulated from the digester through the exchanger and back to the tank rather than transporting water to a point inside the tank. Raw sludge may also be heated in this system, either separately or with the digester recirculated sludge.

It is common practice to locate the heat exchanger near the boiler to reduce heat loss in transporting the water to the exchanger. Sludge is pumped through a series of pipes submerged in a hot water bath or through coils close to pipes carrying hot water in a spiral heat exchanger (see Figure 4-17).

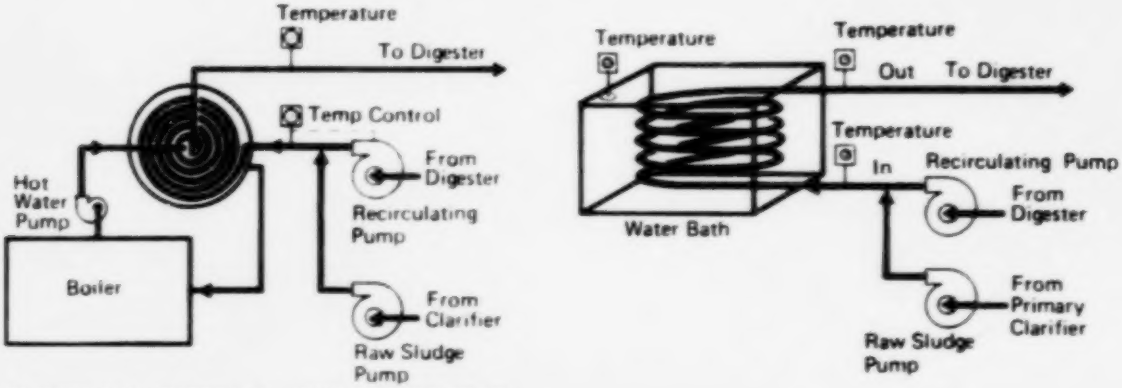

Temperature
To Digester
Temp Control
From Digester
Recirculating Pump
Hot Water Pump
Boiler
From Clarifier
Raw Sludge Pump
Temperature
Temperature
Out
To Digester
Temperature
In
Recirculating Pump
From Digester
Water Bath
From Primary Clarifier
Raw Sludge Pump

FIGURE 4-17 EXTERNAL HEAT EXCHANGERS

Temperature Control Systems. Temperature control systems should be checked for accuracy, such as temperature probes located in digester walls or in sludge pipelines. In the case of probes in sludge pipelines, the operator should consider that:

> Accurate temperatures can only be obtained after the recirculation pump has been running for several minutes. The operator is cautioned not to take readings until the pump has been running long enough for the temperature to stabilize.

Sludge Mixers

Internal Fixed Mixers. A major method of mixing is accomplished by discharging steam, hot gas, or digester gas under the sludge surface and allowing the buoyancy of the rising gas stream to cause movement (see Figure 4-18).

Components of these systems are: a compressor or other device to create pressure higher than the head in the digester, delivery piping, diffusers, and safety and process controls.

Internal Moving Mixers. These mixers use propellers, impellers and turbine wheels to move the sludge, as shown in Figure 4-19.

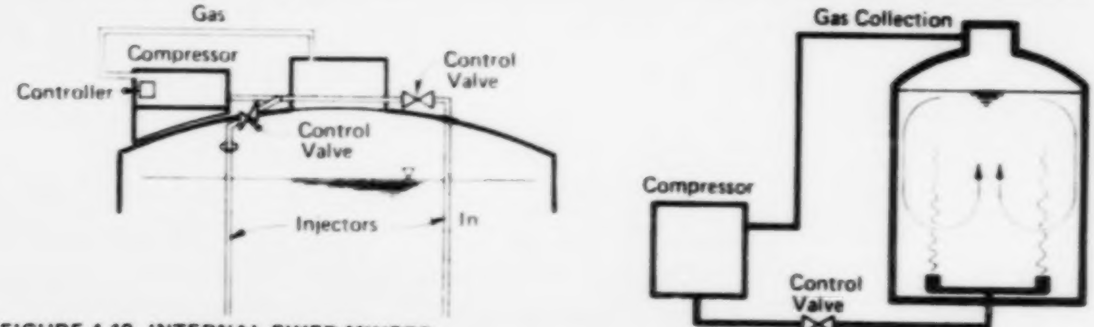

Gas
Compressor
Controller
Control Valve
Control Valve
Injectors
In
Gas Collection
Compressor
Control Valve

FIGURE 4-18 INTERNAL FIXED MIXERS

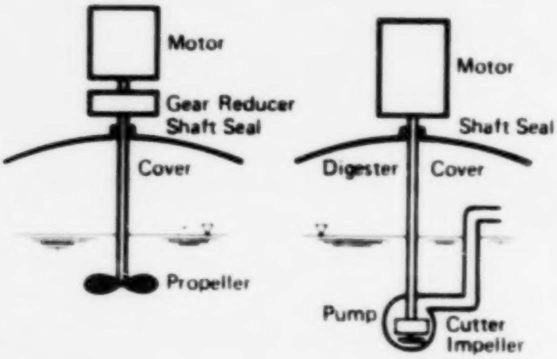


FIGURE 4-19
INTERNAL MOVING MIXERS

An important factor related to this method of mixing is the exposure of moving surfaces to grit and debris. Material that collects around shafts and impellers can cause vibration due to imbalance, and grit wears away impellers. Generally, as the diameter of the rotor increases, the debris problem increases, but wear from grit decreases. On the other hand, small diameter pump impellers or mixing propellers are subject to rapid wear in heavy grit conditions.

Recirculation. Recirculation demands the use of a pump, which may be centrifugal or piston type, and which is located externally from the digester. The total capacity of the pump is generally less than the circulating capacity of mixers. However, some plants use recirculation as the only means of mixing.

Digester Covers

The top surface or cover of a digester has some unique features which merit discussion. Personnel must be aware of how variation in pressure, contents and level inside the tank may affect the cover. Three major types are discussed, fixed, floating and gas holder.

General Comments. The cover on the digester serves several purposes: superstructure for mixing equipment, access to the tank, support for safety devices, space for accumulation and collection of gas and variable storage space for the gas produced. The operator should recognize that precautions must be taken to prevent damage due to excess pressure which may occur when the sludge lines plug and/or gas control devices fail. Damage may also result when vacuum devices fail and movable covers are on the corbels. Fixed covers are vulnerable when the rate of sludge being drawn out exceeds the feed rate, or vacuum devices fail.

Fixed Covers. The biggest hazard in fixed cover operation is encountered when the pressure relief device fails, supernatant overflow line plugs and the liquid level continues to rise. The pressure inside the tank can lift the fixed cover off the walls causing serious damage. The covers may either be concrete structure rigidly fixed to the walls, or metal with anchor bolts securing the cover in one position (see Figure 4-20). In either case, separation from the top of the wall will require

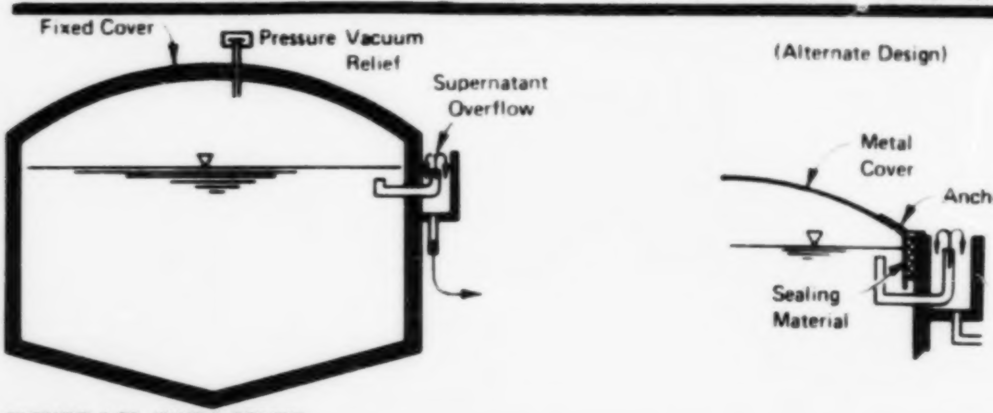


FIGURE 4-20 FIXED COVER

tank draining and expensive repairs.

Floating Covers. Various types of floating covers are in use; however, they have many of the same characteristics and operational problems. Figure 4-21 shows one type. Generally, the cover floats on the surface of the sludge which varies as feeding and supernatant removal rates change.

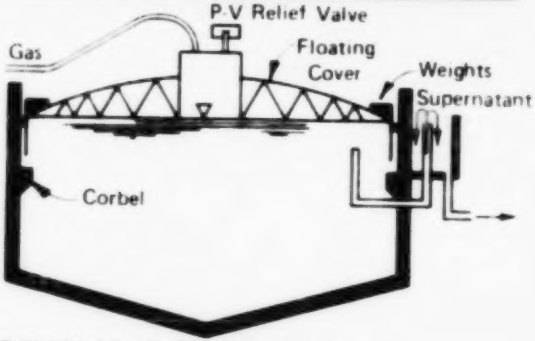


FIGURE 4-21 FLOATING COVER

Maintaining cover guides in smooth operating condition and keeping the cover level are the two main operational concerns with floating covers. For covers with wooden superstructures, replacing the deck and repairing or recovering roofing may also be necessary.

Care must be taken not to pump in excessive amounts of sludge, particularly if plugging of the overflow line is a problem. There have been instances where covers have floated over the wall because of high sludge levels. Covers have also been known to collapse when the vacuum relief failed and the covers were setting on the corbels. Failures of this type are most prevalent during freezing weather.

Gas Holder Covers. The third major type of cover is used to store gas as it is produced. The pressure developed inside the tank causes the cover to lift as much as six feet or more above the minimum height. The cover has a much longer skirt than the floating type (see Figure 4-22).

Stiff metal guides and rollers are mounted between the cover and the wall superstructure to allow the cover to travel up and down without binding. Accumulation of heavy scum around the edge between the cover and the walls can cause excessive friction and prevent free travel. Pressure and vacuum relief valves must also be kept in good operating condition to maintain the desired pressure.

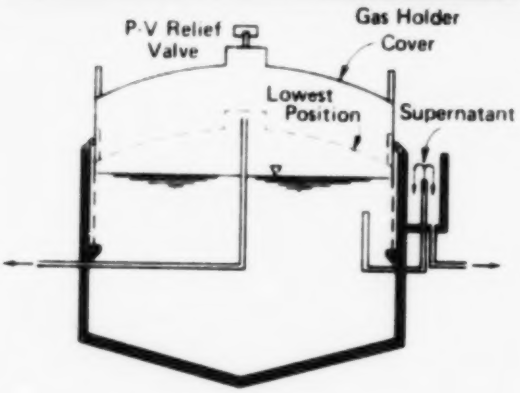


FIGURE 4-22 GAS HOLDER COVER

Gas Handling Equipment and Control Devices

Figure 4-23, Typical Flow and Installation Diagram—Digester Gas System, shows many of the major pieces of equipment in a gas collection and distribution system.

1. **Pressure Relief Device.** The pressure relief device allows excess pressure to escape from the digester in the event that a blockage occurs and pressures build up above a safe level. Troubleshooting information has been given in Part I, Troubleshooting Guides 10 and 11 on digester covers.

2. **Vacuum Breakers.** The vacuum breaker functions opposite to the pressure relief valves and allows air to enter the tank in the event that sludge is drawn out of the tank too rapidly or the level of the sludge changes suddenly with relation to the floating cover. Troubleshooting information is given in Troubleshooting Guides 10 and 11.

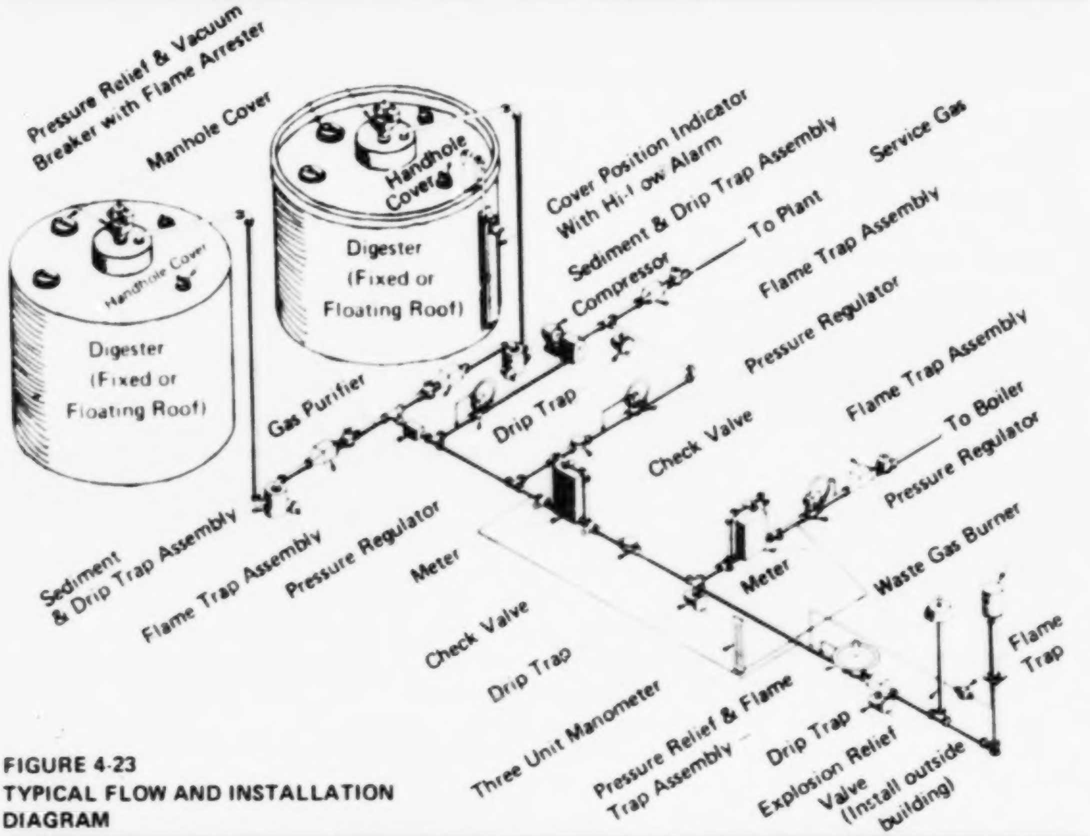

Pressure Relief & Vacuum Breaker with Flame Arrester
Manhole Cover
Handhole Cover
Digester (Fixed or Floating Roof)
Handhole Cover
Digester (Fixed or Floating Roof)
Cover Position Indicator With Hi-Low Alarm
Sediment & Drip Trap Assembly
Service Gas
To Plant
Compressor
Flame Trap Assembly
Pressure Regulator
Gas Purifier
Drip Trap
Check Valve
Flame Trap Assembly
To Boiler
Pressure Regulator
Sediment & Drip Trap Assembly
Flame Trap Assembly
Pressure Regulator
Meter
Check Valve
Drip Trap
Meter
Waste Gas Burner
Flame Trap
Three Unit Manometer
Pressure Relief & Flame Trap Assembly
Drip Trap
Explosion Relief Valve (Install outside building)

FIGURE 4-23
TYPICAL FLOW AND INSTALLATION DIAGRAM

3. **Sediment and Drip Trap Assembly.** Water that condenses in gas lines is normally taken out at the low points in drip traps. This water should be removed daily or more frequently when condensation rates are high. Gas seals sometimes leak due to drying out of the material; therefore, these should be checked monthly and the entire unit disassembled and inspected annually.

4. **Flame Trap Assembly.** Flame traps are installed in lines to prevent flames traveling up the gas line and reaching the digester. The trap consists of a metal grid which allows the gas to cool down below the combustion point as it passes through the metal grid. If a high amount of impurities is in the gas, the metal grid may become fouled and prevent gas passing through. These units should be disassembled annually and washed out in a safe solvent. Refer to the manufacturer's instructions for specific details.

5. **Pressure Regulator.** When gas is used, a lower pressure than the system operating pressure may be needed. Regulators are installed to maintain a constant pressure at the point of use. The pressure regulator can be adjusted to values less than system pressures; however, adjustments should be made following the manufacturer's instructions.

6. **Gas Meter.** Several types of gas meters are in use in treatment plants. These can be a useful tool or an exasperating headache depending on where they are installed and the difficulties in keeping them operating. Several of these are discussed below:

    a. **Bellows Type Meter.** The bellows meter is most similar to the device that the old fashioned blacksmith used to provide air for his fire.

    b. **Shunt-Flow Meter.** This meter, which has a propeller in it, allows a certain amount of gas to bypass the main section of the meter while a measured amount passes through the meter.

    c. **Positive Displacement Type Meter.** This meter operates like a gear motor or in reverse of a lobe type blower. Internal moving parts turn in direct ratio to the amount of gas passing through them. Some operators maintain a spare unit for emergencies.

7. **Check Valve.** When dual gas systems are used (such as a dual fuel engine), check valves are installed to prevent flow of the higher pressure gas back to the digester. These are built to allow flow in one direction only and should be inspected and cleaned annually to assure that all moving parts are free of corrosion and debris.

8. **Manometers.** Gas pressure is measured by a glass column, which contains a special oil or water. These columns are called manometers. The measured pressure is read in inches of water column.

Several sources of information are available for discussions on gas systems. The reader is referred to the ***Operation of Wastewater Treatment Plants—A Field Study***, Chapter 8, pages 8.17 to 8.40, for more detailed discussion and pictures of the devices described above.

APPENDIX

A – GLOSSARY

B – REFERENCES

C – PLANTS VISITED

D – METRIC CONVERSION EQUIVALENTS

E – DIGESTER TEST PROCEDURES

F – FORMULAS

G – DATA REVIEW AND GRAPHING

H – WORK SHEETS

APPENDIX A
GLOSSARY

Acid Forming Bacteria—The group of bacteria in a digester that produce volatile acids as one of the by-products of their metabolism. The acids are used as a food source by the methane forming bacteria.

Aerobic—A condition in which "free" or dissolved oxygen is present in the aquatic environment.

Aerobic Bacteria—Bacteria which live and reproduce only in an environment containing oxygen which is available for their respiration (breathing), such as atmospheric oxygen or oxygen dissolved in water. Oxygen combined chemically, such as in water molecules, H_2O, cannot be used for respiration by aerobic bacteria.

Alkaline—The condition of water, wastewater, or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

Anaerobic—A condition in which "free" or dissolved oxygen is **not** present in the aquatic environment.

Anaerobic Bacteria—Bacteria that live and reproduce in an environment containing no "free" or dissolved oxygen. Anaerobic bacteria obtain their oxygen supply by breaking down chemical compounds which contain oxygen, such as sulfates (SO_4).

Anaerobic Decomposition—Decomposition and decay of organic material in an environment containing no "free" or dissolved oxygen.

Anaerobic Digestion—Wastewater solids and water (about 5% solids, 95% water) are placed in a large tank where bacteria decompose the solids in the absence of dissolved oxygen. At least two general groups of bacteria act in balance (1) **Saprophytic** (acid forming) bacteria break down complex solids to volatile acids, and (2) **Methane Fermenters** break down the acids to methane, carbon dioxide, and water.

Antagonistic Compounds—Materials that are added to a digester usually in a solution form that counteract or nullify the toxic effect of certain metals. An example is adding ferric sulfate to counteract copper salts.

Available Volume—The actual volume available in a digester for bacterial action. It is calculated by subtracting the volume occupied by grit and scum from the total digester volume.

Buffer—A measure of the ability or capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water or wastewater for offering a resistance to changes in the pH.

Concentration—(1) The amount of a given substance dissolved in a unit volume of solution. (2) The process of increasing the dissolved solids per unit volume of solution, usually by evaporation of the liquid.

Contact—The action occurring in the digester whereby food and bacteria are intermixed, allowing the food to be taken into the cell.

Degradation—The breakdown of substances by biological action.

Detention Time—The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

Digester—A tank in which sludge is placed to allow sludge digestion to occur. Digestion may occur under anaerobic (more common) or aerobic conditions.

Draft Tube—An extension of the impeller passage in a hydraulic turbine from the point where the sludge leaves such passages down to the bottom of the tube as part of the mixing system in a high-rate sludge digestion tank.

Enzyme—A catalyst produced by living cells. All enzymes are proteins, but not all proteins are enzymes.

Facultative—Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

Grit—The heavy mineral material present in wastewater such as sand, eggshells, gravel, and cinders.

Imhoff Cone—A clear, cone-shaped container marked with graduations used to measure the volumetric concentration of settleable solids in wastewater.

Inhibitory Toxicity—Any demonstrable inhibitory action of a substance on the rate of general metabolism (including rate of reproduction) of living organisms.

Inorganic Waste—Waste material such as sand, salt, iron, calcium, and other mineral materials which are not converted in large quantities by organism action. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes are chemical substances of animal or vegetable origin and contain mainly carbon and hydrogen along with other elements.

Load Factor—The ratio of the average load carried by an operation to the maximum load carried, during a given period of time, expressed as a percentage. The load may consist of almost anything, examples are electrical power, number of persons served, or amount of volatile solids added in proportion to solids in a digester.

Manometer—Usually a glass tube filled with a liquid and used to measure the difference in pressure across a flow measuring device such as an orifice or venturi meter.

Mesophilic Bacteria—Medium temperature; a group of bacteria that thrive in a temperature range between 68 and 113 degrees Fahrenheit.

Methane Forming Bacteria—The group of bacteria in a digester that use volatile acids as a food source and produce methane as a by-product.

Muffle Furnace—A small oven capable of temperatures up to 550 degrees Celsius (centigrade) and used in laboratories for burning or incinerating samples to determine their loss on ignition (volatile) or fixed solids (ash) content.

Organic Waste—Waste material which comes from animal or vegetable sources. Organic waste generally can be consumed by bacteria and other small organisms. Inorganic wastes are chemical substances of mineral origin and may contain carbon and oxygen, whereas organic wastes contain mainly carbon and hydrogen along with other elements.

Pathogenic Organisms—Bacteria or viruses which can cause disease (typhoid, cholera, dysentery). There are many types of bacteria which do not cause disease and which are **not** called pathogenic. Many beneficial bacteria are found in wastewater treatment processes actively cleaning up organic wastes.

Septic—A condition produced by the growth of anaerobic organisms. If severe, the wastewater turns black, giving off foul odors and creating a heavy oxygen demand.

Settleable Solids—That matter in wastewater which will not stay in suspension during a preselected settling period, such as one hour, and settles to the bottom. In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in one hour.

Sludge—The settleable solids separated from liquids during processing or deposits on bottoms of streams or other bodies of water.

Sludge Digestion—A process by which organic matter in sludge is gasified, liquified, mineralized, or converted to a more stable form by anaerobic (more common) or aerobic organisms.

Sludge Gasification—A process in which soluble and suspended organic matter is converted into gas. Sludge gasification will form bubbles of gas in the sludge and cause large clumps of sludge to rise and float on the water surface.

Supernatant—Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the scum on the surface of an anaerobic digester. This liquid is usually returned to the influent wet well or the primary clarifier.

Suspended Solids—Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering.

Thief Hole—A digester sampling well.

Toxicity—A condition that may exist in wastes that will inhibit or destroy the growth or function of any organism.

Total Solids—The sum of dissolved and suspended constituents in water or wastewater, usually stated in milligrams per liter.

Volatile Acids—Fatty acids which are produced by acid forming bacteria and which are soluble in water. They can be steam-distilled at atmospheric pressure. Volatile acids are commonly reported as equivalent to acetic acid.

Volatile Matter—Apparent loss of matter from a residue ignited at 550 degrees plus or minus 25 degrees Celsius (centigrade) for a period of time sufficient to reach constant weight of residue, usually 10-15 minutes.

Volatile Solids—The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 550 degrees Celsius (centigrade).

APPENDIX B
SUGGESTED READING AND REFERENCES

BASICS

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* Available for purchase from Dr. Kenneth D. Kerri, Department of Civil Engineering, California State University—Sacramento, 6000 Jay Street, Sacramento, California 45819.

** Available for purchase from the Water Pollution Control Federation, 3900 Wisconsin Avenue, Washington, D.C. 20016.

APPENDIX C
PLANTS VISITED

Plant	Size	Type of Plant				Type Cover			Type of Mixing				Type of Heating		
	mgd	Primary	Activated Sludge	Trickling Filter	Number of Digesters	None	Fixed	Floating	External	Gas	Draft Tube	None	External	Internal	None
Vermont															
[illegible]	[illegible]		x		[illegible]		1	1			x		x		
[illegible]	[illegible]	x			1	x						x			x
Rutland	[illegible]	x			[illegible]		1	1			x		x		
[illegible]															
[illegible]	[illegible]			x	2		2				x		x		
[illegible]	[illegible]			x	[illegible]		1	1		x			x		
[illegible]	4		x		2		2			x			x		
Connecticut															
Hartford	[illegible]			x	[illegible]		[illegible]			x			x		
Ohio															
Rocky River	10	x			[illegible]		[illegible]	1			x		x		
[illegible]	7		x		[illegible]			2	x				x		
[illegible]	[illegible]		x		[illegible]		1	1	x					x	
[illegible]	[illegible]				[illegible]		1	1		x			x		
[illegible]	7		x		1		1		x				x		
[illegible]	8		x		[illegible]		[illegible]	[illegible]		x				x	
[illegible]	[illegible]			x	1	x						x			x
[illegible]	50		x		[illegible]		1	1		x				x	
[illegible]	[illegible]		x		34	[illegible]		16	x				x	x	
[illegible]															
[illegible]		x						1	x				x		
[illegible]			x			x						x			x
[illegible]				x			[illegible]					x			x
[illegible]	[illegible]		x				[illegible]			x				x	
[illegible]															
[illegible]				x			1	1	x				x		
[illegible]	[illegible]			x	[illegible]		[illegible]	4	x				x		
[illegible]															
[illegible]															
[illegible]	350		x		[illegible]		[illegible]			x				x	
[illegible]	100														
[illegible]															
Portland	[illegible]		x		[illegible]			4		x			x	x	
[illegible]															
[illegible]	[illegible]		x		[illegible]			[illegible]		x			x		
[illegible]															
[illegible]	[illegible]		x		[illegible]			[illegible]		x			x		
[illegible]	7		x		[illegible]		2	[illegible]		x			x		
[illegible]															
[illegible]	[illegible]			x	[illegible]		1	2	x				x		

APPENDIX D
METRIC EQUIVALENTS

METRIC CONVERSION TABLES

Recommended Units

Description	Unit	Symbol	Comments	English Equivalents
Length	meter	m	Basic SI unit	39.37 in. = 3.28 ft = 1.09 yd
	kilometer	km		0.62 mi
	millimeter	mm		0.03937 in.
	centimeter	cm		0.3937 in.
	micrometer	μm		3.937 × 10⁻⁵ in. = 10⁴A
Area	square meter	m²		10.744 sq ft = 1.196 sq yd
	square kilometer	km²		6.384 sq mi = 247 acres
	square centimeter	cm²		0.155 sq in.
	square millimeter	mm²		0.00155 sq in.
	hectare	ha	The hectare (10 000 m²) is a recognized multiple unit and will remain in international use	2.471 acres
Volume	cubic meter	m³		35.314 cu ft = 1.3079 cu yd
	cubic centimeter	cm³		0.061 cu in.
	liter	l	The liter is now recognized as the special name for the cubic decimeter	1.057 qt = 0.264 gal = 0.81 × 10⁻⁴ acre ft
Mass	kilogram	kg	Basic SI unit	2.205 lb
	gram	g		0.035 oz = 15.43 gr
	milligram	mg		0.01543 gr
	tonne	t	1 tonne = 1,000 kg	0.984 ton (long) = 1.1023 ton (short)
Time	second	s	Basic SI unit. Neither the day nor the year is an SI unit but both are important	
	day	day		
	year	yr or a		
Force	newton	N	The newton is that force that produces an acceleration of 1 m/s² in a mass of 1 kg	0.22481 lb (weight) = 7.5 poundals

Recommended Units

Description	Unit	Symbol	Comments	English Equivalents
Velocity linear	meter per second	m/s		3.28 fps
	millimeter per second	mm/s		0.00328 fps
	kilometers per second	km/s		2,230 mph
angular	radians per second	rad/s		
Flow (volumetric)	cubic meter per second	m³/s	Commonly called the cumec	15,850 gpm = 2,120 cfm
	liter per second	l/s		15.85 gpm
Viscosity	poise	poise		0.0672 lb/sec ft
Pressure	newton per square meter	N/m²	The newton is not yet well known as the unit of force and kgf/cm² will clearly be used for some time. In this field the hydraulic head expressed in meters is an acceptable alternative	0.00014 psi
	kilonewton per square meter	kN/m²		0.145 psi
	kilogram (force) per square centimeter	kgf/cm²		14.223 psi
Temperature	degree Kelvin	K	Basic SI unit. The Kelvin and Celsius degrees are identical. The use of the Celsius scale is recommended as it is the former centigrade scale	$\frac{5F}{9} - 17.77$
	degree Celsius	C		
Work, energy, quantity of heat	joule	J	1 joule = 1 N-m	2.778 × 10⁻⁷ kw-hr = 3.725 × 10⁻⁷ hp-hr = 0.73756 ft-lb = 9.48 × 10⁻⁴ Btu
	kilojoule	kJ		2.778 kw-hr
Power	watt	W	1 watt = 1 J/s	
	kilowatt	kW		
	joule per second	J/s		

Application of Units

Description	Unit	Symbol	Comments	English Equivalents
Precipitation, run-off, evaporation	millimeter	mm	For meteorological purposes it may be convenient to measure precipitation in terms of mass/unit area (kg/m²). 1 mm of rain = 1 kg/sq m	
River flow	cubic meter per second	m³/s	Commonly called the cumec	35.314 cfs
Flow in pipes, conduits, chanels, over weirs, pumping	cubic meter per second	m³/s		
	liter per second	l/s		15.85 gpm
Discharges or abstractions, yields	cubic meter per day	m³/day	1 l/s = 86.4 m³/day	1.83 × 10⁻³ gpm
	cubic meter per year	m³/yr		
Usage of water	liter per person per day	l/person/day		0.264 gpcd
Density	kilogram per cubic meter	kg/m³	The density of water under standard conditions is 1,000 kg/m³ or 1,000 g/l	0.0624 lb/cu ft

Application of Units

Description	Unit	Symbol	Comments	English Equivalents
Concentration	milligram per liter	mg/l		1 ppm
BOD loading	kilogram per cubic meter per day	kg/m³day		0.0624 lb/cu ft day
Hydraulic load per unit area e.g. filtration rates	cubic meter per square meter per day	m³/m²/day	If this is converted to a velocity, it should be expressed in mm/s (1 mm/s = 86.4 m³/m² day)	3.28 cu ft/sq ft
Hydraulic load per unit volume e.g. biological filters, lagoons	cubic meter per cubic meter per day	m³/m³day		
Air supply	cubic meter or liter of free air per second	m³/s l/s		
Pipes diameter length	millimeter meter	mm m		0.03937 in. 39.37 in. = 3.28 ft
Optical units	lumen per square meter	lumen/m²		0.092 ft candle/sq ft

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APPENDIX E
DIGESTER TEST PROCEDURES

LIST OF TESTS

Determination of Volatile Acids in Wastewater Sludge
Alkalinity of Wastewater and Sludge
Sludge Solids (Total Solids and Volatile Solids)
Settleable Matter (Imhoff Cone Test)
Sludge (Digested) Dewatering Characteristics
Supernatant [illegible] Evaluation
Gas Analysis

ALKALINITY OF WASTEWATER AND SLUDGE

Reference: (*Standard Methods*, 14th Edition, [illegible]

[illegible] samples must be settled so that a liquid portion (supernatant) is available for the test. Tests cannot be calculated correctly if solids are in the sample. All samples must be kept cool and tested as soon as possible.

What is Tested?

Sample	Common Range
[illegible]	[illegible] to [illegible] mg/L

Apparatus

1. Centrifuge and centrifuge (tubes or settling cylinder).
2. Graduated cylinders (25 ml and 100 ml) [illegible] Buret(s).
3. 250-ml Erlenmeyer flask or 250-ml beaker.
4. pH meter, or a methyl orange (bromcresol green) indicator may be used (see Procedure).

Reagents

For preparation consult *Standard Methods* or purchase prepared.

1. Sulfuric acid, 0.1 N, which is sufficient for alkalinities ranging from 500-6,000 mg/L. Cautiously add 2.8 ml of concentrated sulfuric acid (H_2SO_4) to 300 ml of distilled water. Dilute to one liter with boiled and cooled distilled water. Standardize against 0.10 N sodium carbonate (Step 2).

2. Sodium Carbonate, 0.10 N. Dry in oven before weighing. Dissolve 5.300 g of anhydrous sodium carbonate (Na_2CO_3) in boiled and cooled distilled water and dilute to one liter with distilled water.

3. Methyl orange (bromcresol green) indicator. Dissolve 0.05 g methyl orange in 100 milliliters of distilled water.

Procedure

This procedure is followed to measure the alkalinity of a sample and also the alkalinity of a distilled water blank.

1. Take a clean 250 ml beaker and add 100 ml or less of clear supernatant (in case of water or distilled water, use 100 ml sample). Select a sample volume that will give a usable titration volume. If the liquid will not separate from the sludge by standing and a centrifuge is not available, use the top portion of the sample. This **same sample** and titrate should be used for both the total alkalinity test and the volatile acids test.

2. If digester alkalinity tends to be above 3,000 mg/l, adjust sample size to between 25 and 50 ml.

3. Place the electrodes of pH meter into the 250 ml beaker containing the sample.

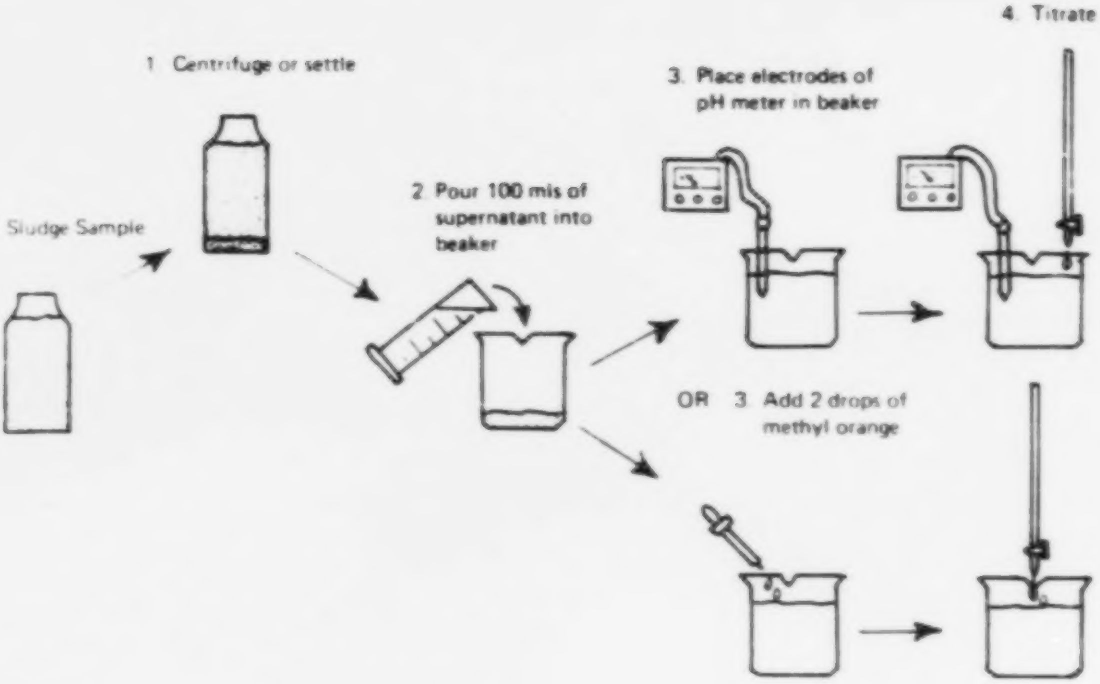
4. Titrate to a pH of 4.5 with 0.10 N sulfuric acid. (In case of a lack of pH meter, add five drops of methyl orange indicator. In this case, titrate to the first permanent change of color to a red-orange color. Care must be exercised in determining the change of color and your ability to detect the change will improve with experience.)

5. Calculate alkalinity as mg/l $CaCO_3$.

Calculation Example

Where: B = 38.0 mls
N = 0.10
Sample size = 100 mls

$$= \frac{38.0 \times 0.1 \times 50{,}000}{100}$$


4. Titrate
1. Centrifuge or settle
3. Place electrodes of pH meter in beaker
2. Pour 100 mls of supernatant into beaker
Sludge Sample
OR 3. Add 2 drops of methyl orange

Formula:

$$\text{Alkalinity (mg/l)} = \frac{B \times N \times 50{,}000}{\text{mls of sample}}$$

Where: B = mls of H_2SO_4 required to titrate sample to pH 4.5
N = Normality of H_2SO_4, i.e., 0.1 N

DETERMINATION OF VOLATILE ACIDS IN WASTEWATER SLUDGE

What is Tested?

Sample	Desired Range
[illegible] sludge	150-600 mg/l (expect trouble if alkalinity less than two times volatile acids)

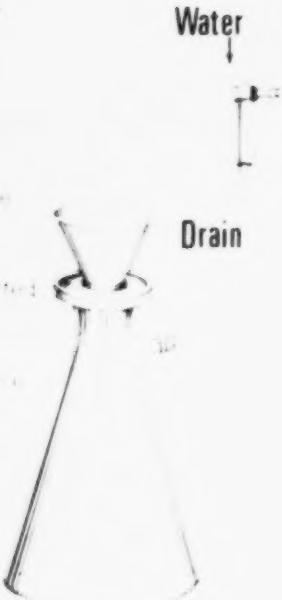
Method A (Silicic Acid Method)

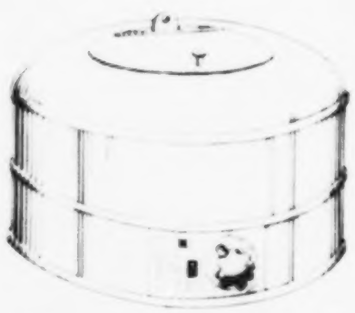
(Standard Methods, 13th Edition, p. 577)

If an aqueous sample containing volatile acids is acidified on a silicic acid column and an organic solvent is passed through the column, the volatile acids will be extracted from the aqueous sample. The extracted acids then can be determined by titration with a base dissolved in methyl alcohol.

Apparatus.

1. Centrifuge or filtering apparatus
2. Two 50 ml graduated cylinders
3. Two medicine droppers
4. Crucibles, Gooch or fritted glass
5. Filter flask
6. Vacuum source
7. One 50 ml beaker
8. Two 5 ml pipettes
9. Burette
10. 1l separatory funnel

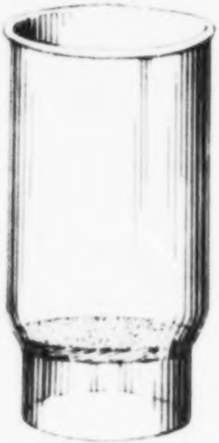




Centrifuge or vacuum filter 50 ml of sludge.

Reagents.

1. Silicic acid solids, 100-mesh. Remove fines from solid portion of acid by slurrying the acid in distilled water and removing the supernatant after allowing settling for 15 minutes. Repeat the process several times. Dry the washed acid solids in an oven at 103°C until absolutely dry and then store in a desiccator.
2. Chloroform-butanol reagent. Mix 300 ml chloroform, 100 ml n-butanol, and 80 ml 0.5 N H_2SO_4 in separatory funnel and allow the water and organic layers to separate. Drain off the lower organic layer through filter paper into a dry bottle.
3. Thymol blue indicator solution. Dissolve 80 mg thymol blue in 100 ml absolute methanol.
4. Phenolphthalein indicator solution. Dissolve 80 mg phenolphthalein in 100 ml absolute methanol.
5. Sulfuric acid, concentrated.
6. Standard sodium hydroxide titrant, 0.02 N. Dilute 20 ml 1.0 N NaOH stock solution to 1 liter with absolute methanol. The stock is prepared in water and standardized against 50 mls of 0.1 N H_2SO_4 as prepared in the alkalinity test, using five drops of phenolphthalein indicator as an endpoint detection. It will require approximately 5.0 mls of 1.0 N NaOH stock to titrate and concentrations should be adjusted so that it takes exactly 5.0 mls.



A fritted-glass filtering crucible is used in the volatile acid determination.

Procedure.

1. Centrifuge or filter enough sludge to obtain a sample of 10 to 15 ml. This **same sample** and filtrate should be used for both the volatile acids test and the total alkalinity test.

2. Measure volume (10 to 15 ml) of sample and place in a beaker.

   Volume of sample, B = ______ ml

3. Add a few drops of thymol blue indicator solution.

4. Add concentrated H_2SO_4, dropwise, until sample just turns red or use pH paper to a pH of 1.0 to 1.2.

5. Place 12 grams of silicic acid (solid acid) in crucible and apply suction. This will pack the acid material and the packed material is sometimes called a column.

6. With a pipette, distribute 5.0 ml acidified sample (from Step 4) as uniformly as possible over the column. Apply suction briefly to draw the acidified sample into the silicic acid column. Release the vacuum as soon as the sample enters the column.

7. Quickly add 65 ml chloroform-butanol reagent to the column.

8. Apply suction and stop just before the last of the reagent enters the column.

9. Remove the filter flask from the crucible.

10. Add a few drops of phenolphthalein indicator solution to the liquid in the filter flask.

11. Titrate with 0.02 N NaOH titrant in absolute methanol, taking care to avoid aerating the sample (discard when white precipitate forms). Nitrogen gas or CO_2–free air delivered through a small glass tube may be used both to mix the sample and to prevent contact with atmospheric CO_2 during titration (CO_2–free air may be obtained by passing air through ascarite or equivalent).

    Volume of NaOH used in sample titration,
    a = ______ ml

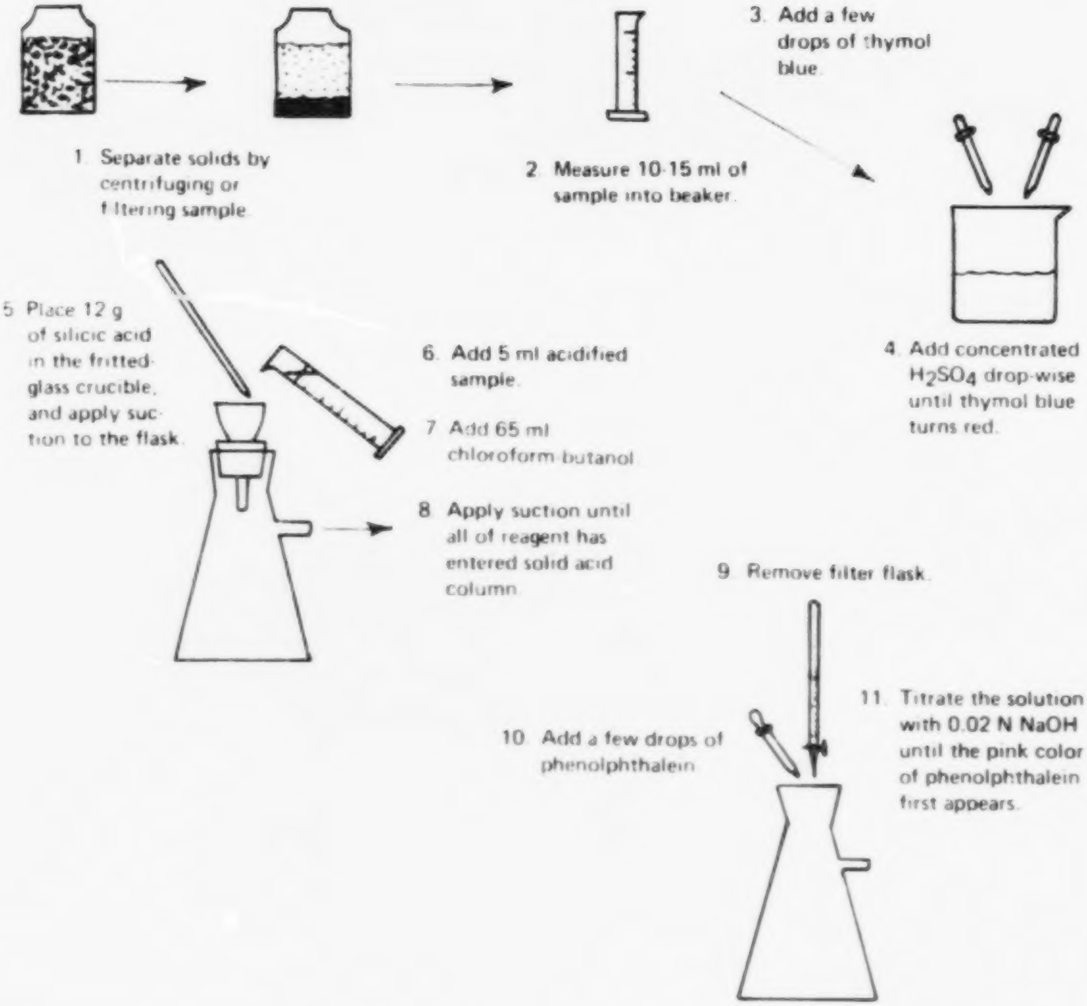
12. Repeat the above procedure using a blank consisting of 5.0 mls of acidified distilled water, extract with reagent and titrate in a similar manner.

    Volume of NaOH used in blank titration,
    b = ______ ml

Precautions.

1. The sludge sample must be representative of the digester. The sample line should be allowed to run for a few minutes before the sample is taken. The sample temperature should be as warm as the digester itself.

2. The sample for the volatile acids test should not be taken immediately after charging the digester with raw sludge. Should this be done, the raw sludge may


1. Separate solids by centrifuging or filtering sample.
2. Measure 10-15 ml of sample into beaker.
3. Add a few drops of thymol blue.
4. Add concentrated H_2SO_4 drop-wise until thymol blue turns red.
5. Place 12 g of silicic acid in the fritted-glass crucible, and apply suction to the flask.
6. Add 5 ml acidified sample.
7. Add 65 ml chloroform-butanol.
8. Apply suction until all of reagent has entered solid acid column.
9. Remove filter flask.
10. Add a few drops of phenolphthalein.
11. Titrate the solution with 0.02 N NaOH until the pink color of phenolphthalein first appears.

shortcircuit to the withdrawal point and result in the withdrawal of raw sludge rather than digested sludge. Therefore, after the raw sludge has been fed into the tank, the tank should be well mixed by recirculation or other means before a sample is taken.

If a digester is performing well with low volatile acids and then if one sample should unexpectedly and suddenly give a high value, say over 1,000 mg/l of volatile acids, do not become alarmed. The high result may be caused by a poor, nonrepresentative sample of raw sludge instead of digested sludge. Resample and retest. The second test may give a more typical value. When increasing volatile acids and decreasing alkalinity are observed, this is a definite warning of approaching control problems. Corrective action should be taken immediately, such as reducing the feed rate, reseeding from another digester, maintaining optimum temperatures, improving digester mixing, decreasing sludge withdrawal rate, or cleaning the tank of grit and scum.

Example

Volume of sample, B = 5 mls
Normality of NaOH titrant, N = 0.02 N
Volume of NaOH used in sample titration, a = 1.4 ml
Volume of NaOH used in blank titration, b = 0.5 ml

Calculation.

Volatile Acids, mg/l (as acetic acid)

Formula

$$\frac{(a - b) \times N \times 60{,}000}{\text{mls of sample}}$$

Example

$$\frac{(1.4 - 0.5) \times .02 \times 60{,}000}{5}$$

Method B (Nonstandard Titration Method) Volatile Acid Alkalinity

Apparatus.

1. One pH meter
2. One adjustable hot plate
3. Two Burettes and stand
4. One 100 ml beaker

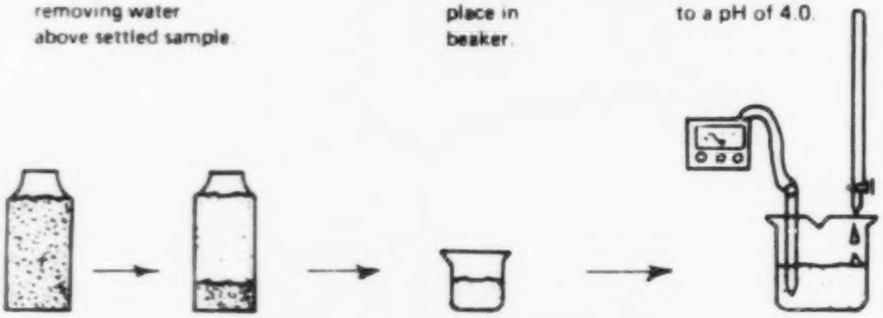
Reagents.

1. pH 7.0 buffer solution
2. pH 4.0 buffer solution
3. Standard acid
4. Standard base

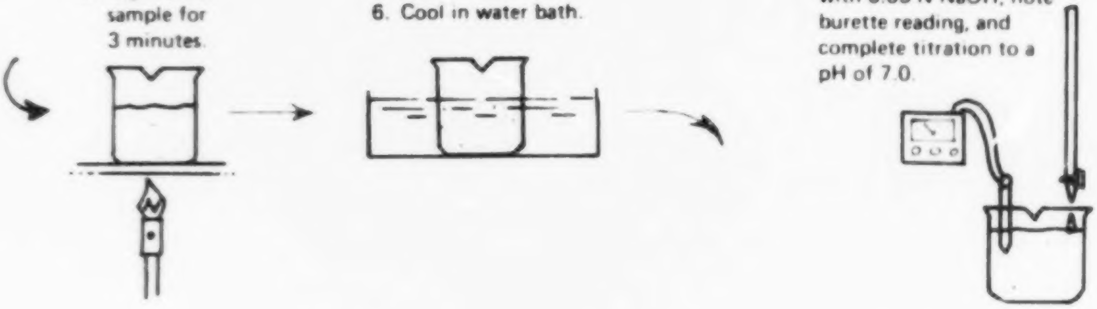
Procedure.

1. Standardize the pH meter with 7.0 buffer and check pH before treatment of sample

1. Separate solids by centrifuging or removing water above settled sample.
2. Measure 50 ml & place in beaker.
3. Titrate with sulfuric acid to a pH of 4.0.
4. Note acid used and continue titrating to pH 3.5 to 3.3.



5. Lightly boil sample for 3 minutes.
6. Cool in water bath.
7. Titrate to pH of 4.0, with 0.05 N NaOH, note burette reading, and complete titration to a pH of 7.0.



to remove the solids. Filtration is not necessary. Decanting (removing water above settled material) or centrifuging sample is satisfactory. Do not add any coagulant aids.

2. Titrate 50 ml of the sample in a 100 ml beaker to pH 4.0 with the appropriate strength sulfuric acid (depends on alkalinity), note acid used, A = _______ ml, and continue to pH 3.5 to 3.3. A magnetic mixer is extremely useful for this titration.

3. Carefully buffer pH meter at 4.00 while lightly boiling the sample a minimum of three minutes. Cool in cold water bath to original temperature.

4. Titrate sample with standard 0.050 N sodium hydroxide up to pH 4.00, and note burette reading, a = _______ ml. Complete the titration at pH 7.0, b = _______ ml. (If this titration consistently takes more than 10 ml of the standard hydroxide, use 0.100 N NaOH.)

5. Calculate total alkalinity. Take answer in mls from Step 2, titration to pH 4.0 and calculate alkalinity according to formula on Alkalinity of Wastewater and Sludge, page E-2, remembering that there will be a discrepancy between titration of sample to pH 4.5 and this titration to 4.0.

6. Calculate volatile acid alkalinity (alkalinity between pH 4.0 and 7.0).

   Volatile Acid Alkalinity, mg/l (as $CaCO_3$)

7. Calculate volatile acids.

   Case 1. > 180 mg/l volatile acid alkalinity
   Volatile Acids = volatile acid alkalinity times 1.50

   Case 2. < 180 mg/l volatile acid alkalinity
   Volatile Acids = volatile acid alkalinity times 1.00

Steps 1 and 2 will give the analyst the pH and total alkalinity, two control tests normally run on digesters. The difference between the total and the volatile acid alkalinity is bicarbonate alkalinity. The time required for Steps 3 and 4 is about 10 minutes.

8. Calculate bicarbonate alkalinity. Volatile acid alkalinity in mg/l (Step 6)–Total Alkalinity in mg/l (Step 5) = Bicarbonate Alkalinity in mg/l.

This is an acceptable method for digester control to determine the volatile acid/alkalinity relationship, but not of sufficient accuracy for research work.

Example and Calculation. Titration from pH 4.0 to 7.0 of a 50 ml sample required 8 ml of 0.05 N NaOH (a = 1.1 ml, b = 9.1 ml).

Step 5. Calculate volatile acid alkalinity (alkalinity between pH 4.0 and 7.0)

Volatile Acid Alkalinity, mg/l

$$= (b - a) \times 2{,}500/50$$

$$= \frac{8\text{ ml} \times 2{,}500}{50\text{ ml}}$$

$$= 400\text{ mg/l}$$

Step 6. Calculate volatile acids.

Case 1. 400 mg/l > 180 mg/l. Therefore,

Volatile Acids, mg/l

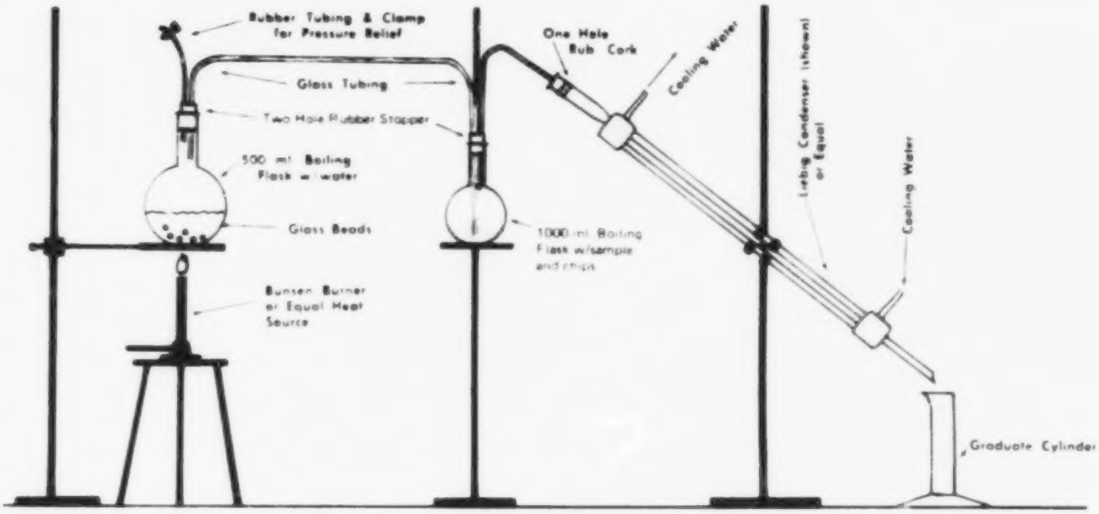
= Volatile acid alkalinity × 1.50
= 400 mg/l × 1.50
= 600 mg/l

Distillation Method.

This method is quite empirical and should be carried out exactly as described. It is not intended for accurate work but satisfactorily serves the purpose of digester control.

1. Centrifuge 200 ml of sample for 5 minutes or allow the sludge sample to settle for approximately one-half hour.
2. Pour off 100 ml of the supernatant liquor in a 500 ml distillation flask.
3. Add 100 ml of water and 4-5 clay chips or similar material to prevent bumping. Add 5 ml concentrated sulfuric acid (H_2SO_4), then mix.
4. Distill off 150 ml at a rate of 5 ml/minute.
5. Titrate with 0.117 N sodium hydroxide, using 4-6 drops of phenolphthalein as an indicator.
6. Titrate to the first general appearance of the pink color.

Volatile Acids = ml sodium hydroxide x 100.


Rubber Tubing & Clamp for Pressure Relief
Glass Tubing
Two Hole Rubber Stopper
500 ml Boiling Flask w/water
Glass Beads
Bunsen Burner or Equal Heat Source
One Hole Rub Cork
Cooling Water
1000 ml Boiling Flask w/sample and chips
Liebig Condenser (shown) or Equal
Cooling Water
Graduate Cylinder

VOLATILE ACIDS SET-UP WITH STEAM GENERATOR

NOTE

The diagram shows the Volatile Acids setup with a steam generator. This method will give more consistent results as the temperature of the sample remains constant and the rate of distillation is then controlled by the rate at which the steam is produced. The alternate method would be to eliminate the steam generator and apply heat directly to the sample flask.

SLUDGE SOLIDS

Reference: (*Standard Methods*, 13th Edition, p. 535)

Total Solids (Sludge)

Definition. Total solids in sludge is a measure of all material present in sludge, both in suspension and in solution. This test is accomplished by evaporating a weighed sample in a drying oven. All the material remaining in a sample after the water has been evaporated is considered as the total solids.

Unlike total solids in wastewater which is expressed in mg/l, total solids in sludge is expressed in terms of percent by weight of the total amount of solids.

Significance. This test is used for wastewater sludges or where the solids can be expressed in percentages by weight, and the weight can be measured on an inexpensive beam balance to the nearest .01 of a gram. The total solids are composed of two components, volatile and fixed solids. Volatile solids are composed of organic compounds which are of either plant or animal origin. Fixed solids are inorganic compounds such as sand, gravel, minerals, or salts.

Volatile Solids

Definition. The volatile solids are that portion of the total solids which will ignite at 550°C. Total volatile solids are usually expressed as a percent of the total solids.

What is Tested?

	Common Range, % by Weight		
Sample	**Total**	**Vol.**	**Fixed**
Raw sludge	6% to 9%	75%	25% ± 6%
Raw sludge + waste activated sludge	2% to 5%	80%	20% ± 5%
Recirculated sludge	1.5% to 3%	75%	25% ± 5%
Supernatant			
Good quality, has suspended solids	1%	50%	50% ± 10%
Poor quality	5%		
Digested sludge to air dry	3% too thin to 8%	50%	50% ± 10%

Apparatus.

1. Evaporating dish
2. Analytical balance
3. Drying oven, 103° - 105°C.
4. Measuring device–graduated cylinder
5. Muffle furnace, 550°C.

Precautions.

1. **Be sure that the sample is thoroughly mixed** and is representative of the sludge being pumped. Generally, where sludge pumping is intermittent, sludge is much heavier at the beginning and is less dense toward the end of pumping. Take several equal portions of sludge at regular intervals and mix for a good sample.

2. Take a large sample (at least 1 l). Measure a 50 or 100 ml sample which approximates 50 or 100 grams into an evaporating dish that has been preweighed. Since this material is so heterogeneous (nonuniform), it

is difficult to obtain a good representative sample with less volume. Smaller volumes will show greater variations in answers due to the uneven and lumpy nature of the material.

3. Control oven temperature closely at 103° to 105°C. Some solids are lost at any drying temperature. Close control of oven temperatures decreases the losses of volatile solids and evaporated water.

4. Heat dish long enough to insure evaporation of water, usually about 3-4 hours. If heat drying and weighing are repeated, stop when the weight change becomes small per unit of drying time. The oxidation, dehydration, and degradation of the volatile fraction won't completely stabilize until it is carbonized or becomes ash.

5. Since sludge is so nonuniform, weighing on the analytical balance should probably be made only to the nearest 0.01 grams or 10 milligrams.

Procedure.

1. Dry the dish by ignition in a muffle furnace at 550°C. for one hour. Cool dish in desiccator.

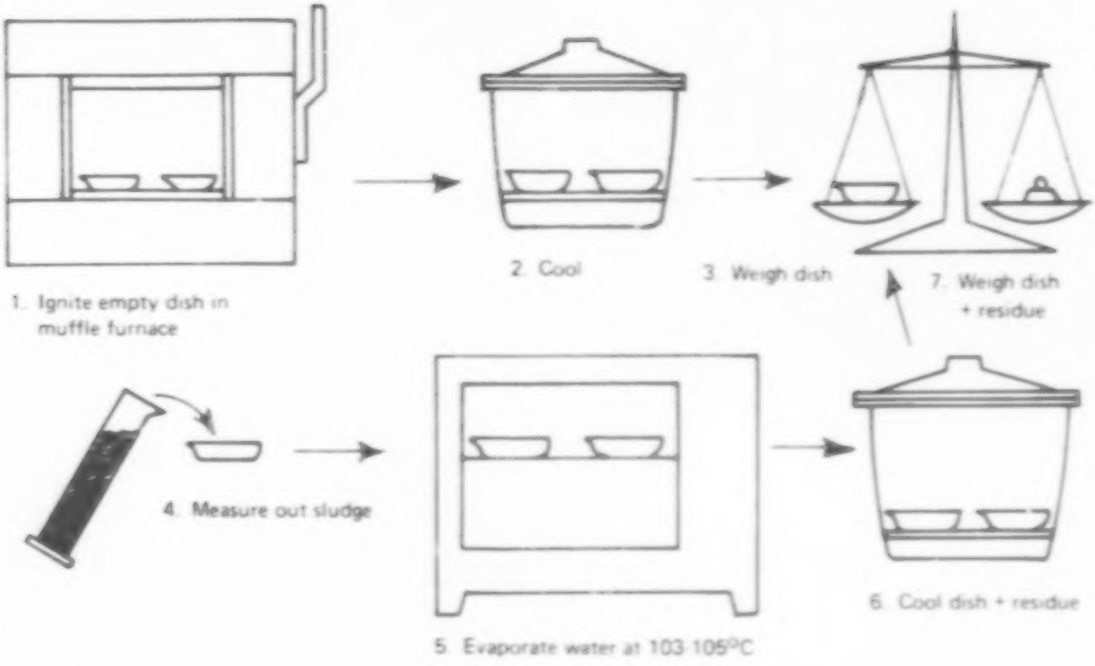
2. Tare the evaporating dish to the nearest 10 milligrams, or 0.01 g on the analytical single pan balance. Record the weight as Tare Weight equals __________ g.

3. Weigh dish plus 50 to 100 ml of **well mixed** sludge sample. Record total weight to nearest 0.01 gram as Gross Weight equals __________ g.

4. Evaporate the sludge sample to dryness in the 103°C. drying oven and place in desiccator to cool to room temperature.

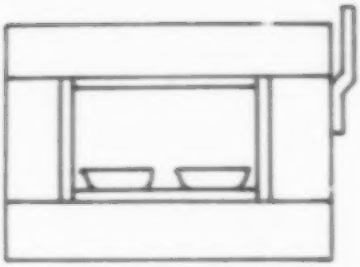
5. Weigh the dried residue in the evaporating dish to the nearest 10 milligrams, or 0.01 g. Record the weight as Dry Sample and Dish equals __________ g.

6. Compute the net weight of the residue by subtracting the tare weight of the dish from the dry sample and dish.



Outline of Procedure for Volatile Solids (continue from total solids test).

1. Determine the total solids as previously described.
2. Ignite the dish and residue from total solids test at 550°C. for one hour or until a white ash remains.
3. Cool in desiccator to room temperature.
4. Weigh and record weight of Dish Plus Ash equals ____________ g


1. Ignite dried solids at 550°C

2. Cool

3. Weigh fixed solids

Total Solids, Volatile Total Solids and Moisture in Sludge

A sample of sludge was tested for solids content. The dish used weighed 8.62 grams when empty and dry, the dish and wet sludge weighed 21.82 grams. After drying the dish overnight at 103-105°C., the dried sludge weighed 9.28 grams. After ignition for one hour at 550°C., the dish plus ash weighed 8.85 grams. What was the percent of solids in the sample, calculate the percent volatile matter and percent moisture?

Type of form to be used.

	Wet	Dry	Ash
Weight of sample & dish, g	21.82	9.28	8.85
Weight of dish, g	8.62	8.62	8.62
Difference	13.20	0.66	0.23

Formula

$$\frac{\text{wt. of dried sludge}}{\text{wt. of wet sludge}} \times 100 = \%\ \text{solids}$$

$$\frac{0.66\ \text{g}}{13.20\ \text{g}} \times 100\% = 5\%$$

Moisture = 100% - % solids = 100% - 5% = 95%

Fixed matter (dry basis)

$$= \frac{\text{wt. of ash}}{\text{wt. of dried sludge}} \times 100$$

$$= \frac{0.23}{0.66} \times 100 = 35\%$$

Volatile matter (dry basis)

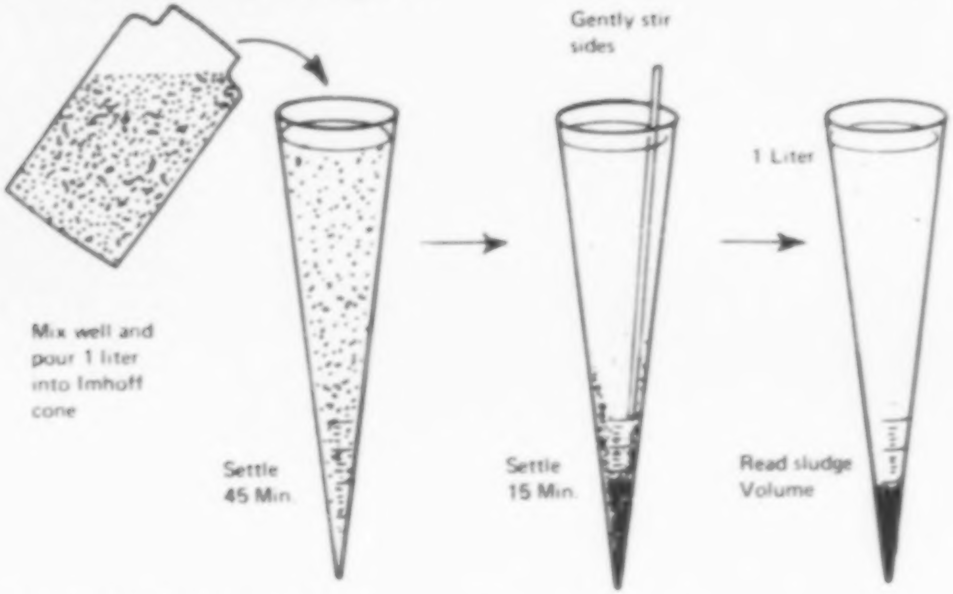
= 100% - % fixed solids
= 100% - 35%
= 65%

Or another way of determining volatile matter is to subtract weight of ash from weight of dried sludge and divide this difference by weight of dried sludge.

% volatile matter equals

$$\frac{\text{wt. of dried sludge} - \text{wt. of ash}}{\text{wt. of dried sludge}} \times 100$$

SETTLEABLE MATTER (IMHOFF CONE TEST)



Reference: (*Standard Methods*, 13th Edition, p. 539)

This simple test can be made to show quickly, visibly and qualitatively if the primary and secondary processes are functioning properly. The volume of settleable solids in the raw waste and effluents is seen readily, and the turbidity removal due to secondary purification processes is evident immediately to the eye. The results are not quantitative but are very illuminating to both the untrained and trained operator.

Apparatus

An Imhoff cone, made either of Pyrex glass or clear plastic material, a cone support, and a long glass stirring rod.

Procedure

1. Fill the Imhoff cone to the one liter mark with a well mixed sample.
2. Settle for 45 minutes and then gently stir the sample with the glass rod to dislodge suspended matter clinging to the tapered sides of the cone.
3. Settle 15 minutes longer, then read the volume of settleable matter in ml/l.

Record the settleable solids as ml/l or milliliters per liter.

Settleable solids, influent = __________ ml/l
Settleable solids, effluent = __________ ml/l
Settleable solids, removal = __________ ml/l

Example: Samples were collected from the influent and effluent of a primary clarifier. After one hour, the following results were recorded.

	Settleable Solids, ml/l
Influent	12.0
Effluent	0.2

Calculations. Calculate the efficiency or percent removal of the above primary clarifier in removing settleable solids.

Percent Removal of Settleable Solids

$$= \frac{\text{infl. set. sol., ml/l} - \text{effl. set. sol., ml/l}}{\text{influent set. sol., ml/l}} \times 100\%$$

$$= \frac{12\ \text{ml/l} - 0.2\ \text{ml/l}}{12\ \text{ml/l}} \times 100\% = 98\%$$

$$= \frac{11.8}{12} \times 100\% \qquad \begin{array}{r} .983 \\ 12\overline{)11.8} \\ \underline{10\ 8} \\ 1\ 00 \\ \underline{96} \\ 40 \end{array}$$

$$= 98\%$$

Estimate the gallons per day of sludge pumped to a digester from the above primary clarifier if the flow is 1 mgd (1 million gallons per day). In your plant, the Imhoff cone may not measure or indicate the exact performance of your clarifier or sedimentation tank, but with some experience you should be able to relate or compare your lab tests with actual performance.

Sludge removed by clarifier, ml/l
= (influent set. sol., ml/l) minus (effluent set. sol., ml/l)
= 12 ml/l minus 0.2 ml/l
= 11.8 ml/l

To estimate the gpd (gallons per day) of sludge pumped to a digester, use the following formula:

Sludge to digester, gpd
= total set. sol. removed, ml/l times 1,000 times flow, mgd (assume for illustration a 1.0 mgd flow)
= 11.8 × 1,000 × 1 = 11,800 gpd

This value may be reduced by 30 to 75% due to compaction of the sludge in the clarifier.

If you figure sludge removed as a percentage (1.18%), the sludge pumped to the digester would be calculated as follows:

$$\frac{1.18\%}{100\%} = \frac{\text{sludge to digester, gpd}}{\text{flow of 1,000,000 gpd}}$$

$$\text{Sludge to digester, gpd} = \frac{1.18\% \times 1{,}000{,}000\ \text{gpd}}{100\%}$$

$$= 11{,}800\ \text{gpd}$$

SLUDGE (DIGESTED) DEWATERING CHARACTERISTICS

Discussion

The dewatering characteristics of digested sludge are very important. The better the dewatering characteristics or drainability of the sludge, the quicker it will dry and the less area will be required for sludge drying beds.

What is Tested?

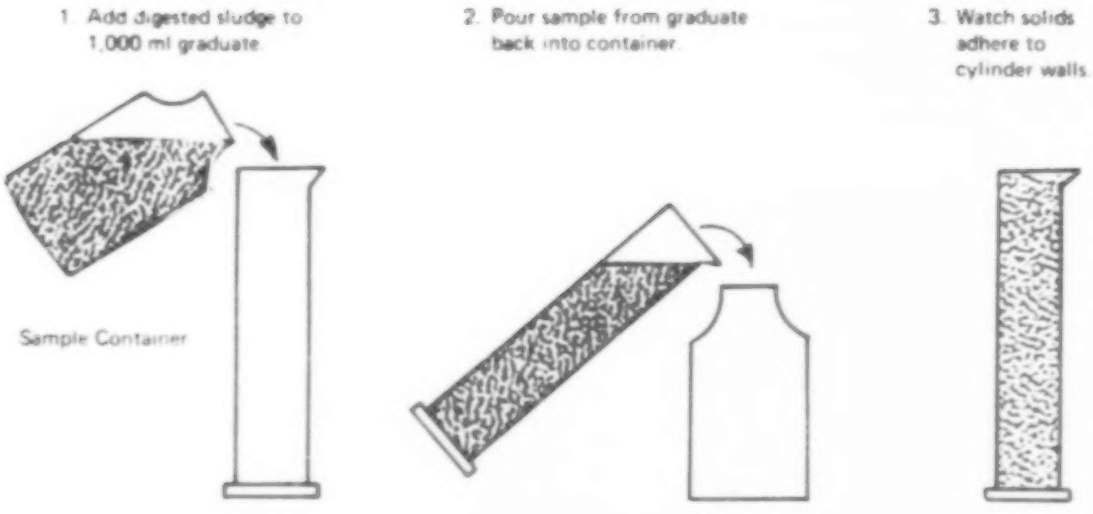
Sample	Preferred Range Method A	Method B
Digested Sludge	Depends on appearance	100-200 ml

Procedure

Two methods are presented in this section. Method A relies on a visual observation and is quick and simple. The only problem is that operators on different shifts might record the same sludge draining characteristics differently. Method B requires 24 hours, but the results are recorded by measuring the volume of liquid that passed through the sand. Method B would be indicative of what would happen if you had sand drying beds.

Apparatus

Method A. 1,000 ml graduated cylinder.


1. Add digested sludge to 1,000 ml graduate.
2. Pour sample from graduate back into container.
3. Watch solids adhere to cylinder walls.
Sample Container

1. Add sample of digested sludge to 1,000 ml graduate.
2. Pour sample back into sample container. Set graduated cylinder down.
3. Watch graduate. If solids adhere to cylinder wall and water leaves solids in form of small streams, this is a **good** dewatering sludge on a sand drying bed.

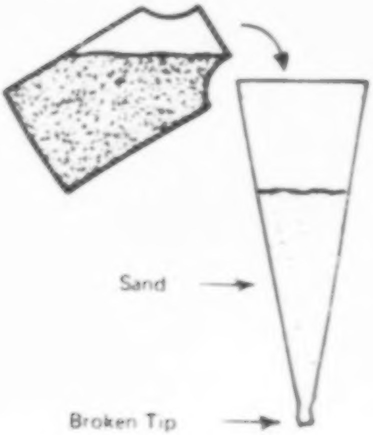
Method B.

1. Imhoff cone with tip removed
2. Sand from drying bed
3. 500 ml beaker

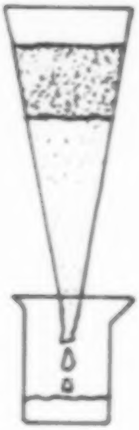
Reagents

None.

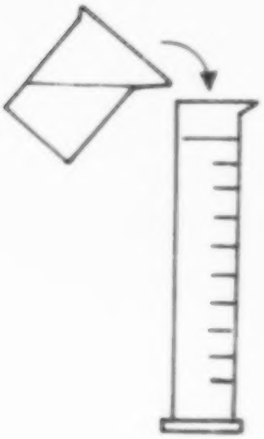
1. Pour digested sludge on top of sand in Imhoff cone



2. Place beaker under tip and wait 24 hrs.



3. Measure liquid that has passed through the sand.



1. Broken glass Imhoff cone that has tip removed and a glass wool plug in the end to hold the sand in the cone.

2. Fill halfway with sand from sand drying bed.

3. Fill remainder to one liter with digested sludge.

4. Place 500 ml beaker under cone tip and wait 24 hours.

5. Record liquid that has passed through sand in ml. If less than 100 ml has passed through sand, you have poor sludge drainability.

Supernatant Graduate Evaluation

Discussion. The digester supernatant solids test measures the percent of settleable solids being returned to the plant headworks. The settleable solids falling to the bottom of a graduate should not exceed the bottom 5% of the graduate in most secondary plants. When this happens, you are imposing a load on the primary settling tanks that they were not designed to handle. If the solids exceed 5% you should run a suspended solids Gooch crucible test on the sample and calculate the recycle load on the plant that is originating from the digester.

What is Tested?

Sample	Common Values
Supernatant	% Solids should be < 5%

Apparatus. 100 ml graduated cylinder.

Reagents. None.

Procedure

1. Fill a 100 ml graduated cylinder with supernatant sample.

2. After 60 minutes, read the ml of solids that have settled to the bottom.

3. Calculate supernatant solids, %.

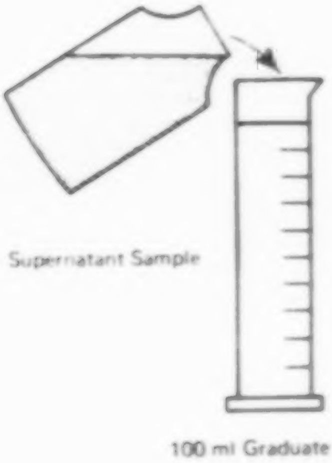
   Supernatant solids, % = ml of solids

Example. Solids on bottom of cylinder, 10 ml.

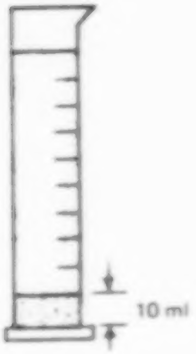
Calculations.

Supernatant Solids, %
= ml of solids
= 10 ml
= 10% solids (high) by volume

1. Fill 100 ml graduate with supernatant.



2. After 60 min., read ml of solids at bottom.



GAS ANALYSIS

Definition

The digester gas analysis is the carbon dioxide content of the digester gas expressed in percent.

Significance

Digester gas production is a direct indication of the activities taking place in a digester. The gas generally analyzes at 30% carbon dioxide and 70% methane. Each plant must develop a history of analysis results. Deviations from the normal trend indicate changes in activities within the digesting sludge. When the operator detects these changes through changing gas analysis, he may perform further and more intensive study of the sludge. The CO_2 content of a properly operating digester will range from 25-35% by volume. If the percent is above 35%, the gas will not burn. The easiest test procedure for determining this change is with a CO_2 analyzer.

Method A (Orsat). The Orsat gas analyzer can measure the concentrations of carbon dioxide, oxygen and methane by volume in digester gas. To analyze digester gas by the Orsat method, follow equipment manufacturer's instructions. This procedure is not recommended for the inexperienced operator.

Method B.

APPARATUS

1. One Bunsen burner
2. Plastic tubing
3. 100 ml graduated cylinder
4. 250 ml beaker

REAGENTS: CO_2 Absorbent (KOH). Add 500 g potassium hydroxide (KOH) per liter of water.

PROCEDURE.

1. Measure total volume of a 100 ml graduate by filling it to the top with water (approximately 125 ml). Record this volume.

2. Pour approximately 125 ml of CO_2 absorbent in a 250 ml beaker.
   CAUTION: Do not get any of this chemical on your skin or clothes. Wash immediately with running water until slippery feeling is gone or severe burns can occur.

3. Collect a representative sample of gas from the gas dome on the digester, a hot water heater using digester gas to heat the sludge, or any other gas outlet. Before collecting the sample for the test, attach one end of a gas hose to the gas outlet and the other end to a Bunsen burner. Turn on the gas, ignite the burner, and allow it to burn digester gas for a sufficient length of time to insure collecting a representative gas sample.

4. With gas running through hose from gas sampling outlet, place hose inside inverted calibrated graduated cylinder and allow digester gas to displace air in graduate. Turn off gas.
   CAUTION: The proper mixture of digester gas and air is explosive when exposed to a flame.

5. Place graduate full of digester gas upside down in beaker containing CO_2 absorbent.

6. Insert gas hose inside upside down graduate.

7. Turn on gas, but **do not blow out liquid** Run gas for at least 60 seconds.

8. Carefully remove hose from graduate with gas still running.

9. **Immediately turn off gas**

10. Wait for ten minutes and shake gently. If liquid continues to rise, wait until it stops.

11. Read gas remaining in graduate to nearest ml.

Example

Total volume of graduate equals 126 ml
Gas remaining in graduate equals 80 ml

CALCULATION

Percent CO_2

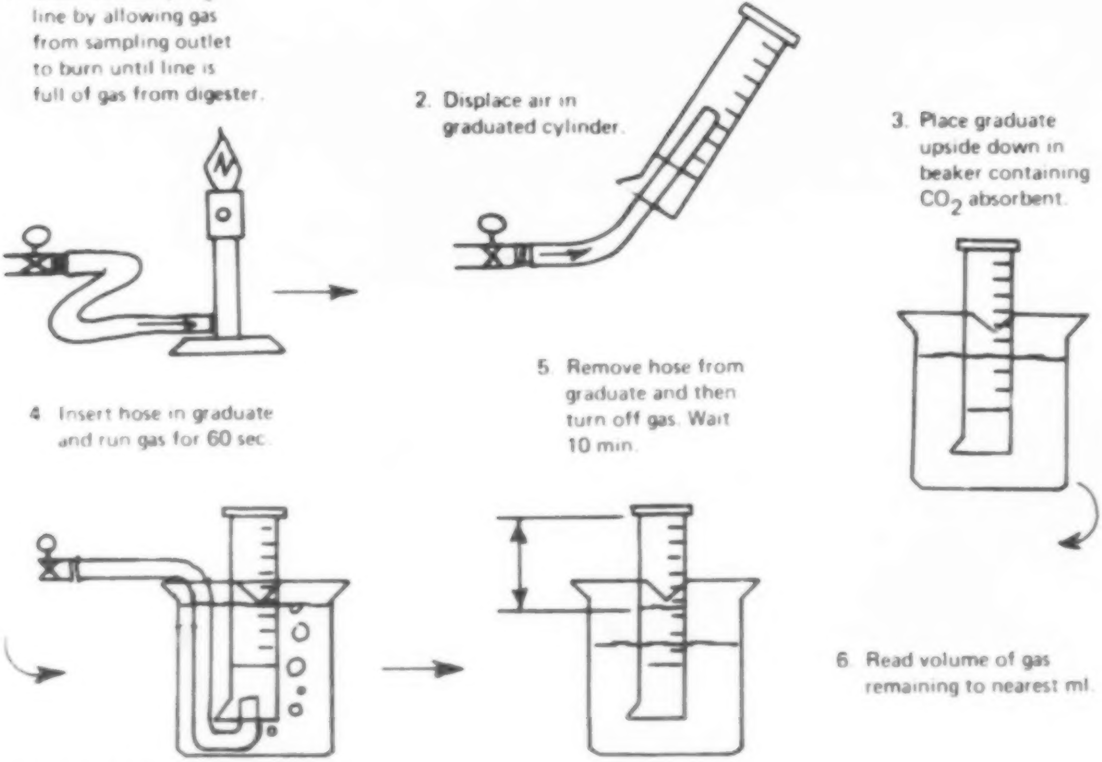
$$= \frac{(\text{total vol., ml} - \text{gas remaining, ml})}{\text{total volume, ml}} \times 100\%$$

$$= \frac{(126\text{ ml} - 80\text{ ml})}{126\text{ ml}} \times 100\%$$

$$= \frac{46}{126} \times 100\%$$

$$= 37\%$$

$$\begin{array}{r} 365 \\ 126\overline{)46.0} \\ 37.8 \\ \hline 8.20 \\ 7.56 \\ \hline 640 \\ 630 \end{array}$$



1. Clean out sampling line by allowing gas from sampling outlet to burn until line is full of gas from digester.

2. Displace air in graduated cylinder.

3. Place graduate upside down in beaker containing CO_2 absorbent.

4. Insert hose in graduate and run gas for 60 sec.

5. Remove hose from graduate and then turn off gas. Wait 10 min.

6. Read volume of gas remaining to nearest ml.

PRECAUTIONS

1. Avoid any open flames near the digester.
2. Work in a well ventilated area to avoid the formation of explosive mixtures of methane gas.
3. If your gas sampling outlet is on top of your digester, turn on outlet and vent the gas to the atmosphere for several minutes to clear the line of old gas. Start with step 2, displace air in graduated cylinder. NEVER ALLOW ANY SMOKING OR FLAMES NEAR THE DIGESTER AT ANY TIME.

APPENDIX F
FORMULAS AND CALCULATIONS USED IN DIGESTER OPERATION AND CONTROL

These are some of the more commonly used formulas and calculations for digester operation and control. They are set up with captions showing general use and the metric conversion is shown with the English unit form of the answer. If no metric equivalent is shown, expression is the same in both systems.

1. **Total Pounds Fed**
   Find total pounds of solids fed to the digester per day.

$$\text{TS}(\%)/100 \times 8.34\ (\text{lbs./gal.}) \times \text{raw sludge (gal./day)} = \text{TS(lbs/day)}\ [\times 0.454 = \text{kg/day}]$$

2. **Volatile Pounds Fed**
   Find pounds of volatile solids fed to the digester per day.

$$\text{Vol.}(\%)/100 \times \text{TS(lbs./day)} = \text{VS (lbs./day)}\ [\times 0.454 = \text{kg/day}]$$

3. **Volatile Solids Loading**
   Find pounds volatile solids per cubic foot of digester capacity per day.

$$\frac{\text{VS (lbs./day)}}{\text{Digester Vol. (cu.ft.)}} = \frac{\text{VS(lbs./day)}}{\text{(cu.ft.)}}\ [\times 16.02 = \frac{\text{kg/day}}{\text{m}^3}]$$

4. **Ash or Inorganic Percent**
   Find percent ash in sludge sample when percent volatile is known.

$$100\% - \text{VS}(\%) = \text{ash}(\%)$$

5. **Ash or Inorganic Solids Fed**
   Find pounds of ash if total solids and percent volatile are known.

$$\text{TS(lbs./day)} \times (100\% - \text{Vol. }\%)/100 = \text{ash(lbs./day)}$$

6. **Hydraulic Detention Time**
   Find time in days for digester volume to be displaced.

$$\frac{\text{Tank Vol. (cu.ft.)} \times 7.5\text{(gal./cu.ft.)}}{\text{raw sludge (gal./day)}} = \text{hydraulic detention time, days}$$

7. **Solids Detention Time (SRT)**
   Find average time in days that solids remain in the digester (NOTE: Use information covering at least a month's averages).

$$\frac{\text{TS in dig. (lbs.)} - \text{supernatant (lbs.)}}{\text{TS in raw sludge fed (lbs./day)}} = \text{solids retention time, days}$$

8. Volatile Solids Reduction

Find percent volatile reduction between feed and sludge disposed of (NOTE – Use percent expressed in decimal equivalent)

$$\frac{\text{VS in (\%)} - \text{VS out (\%)}}{\text{VS in (\%)} - [\text{VS in (\%)} \times \text{VS out (\%)}]} \times 100\% = \text{VS reduction (\%)}$$

9. Volatile Solids Converted

Find pounds of volatile converted to other forms per cubic foot digester volume per day

$$\frac{\text{Sludge pumped (gal./day)} \times \text{TS(\%)} \times \text{Vol. (\%)} \times \text{VS red. (\%)} \times 8.34\text{(lbs./gal.)}}{\text{Volume Digester (cu.ft.)}}$$

$$= \text{VS converted } \frac{\text{(lbs./day)}}{\text{cu.ft.}} \left[\times 16.02 = \frac{\text{kg/day}}{\text{m}^3}\right]$$

10. Gas Produced From Volatile Solids

Find volume gas produced per pound volatile solids converted.

$$\frac{\text{Gas produced (cu.ft./day)}}{\text{Vol. solids converted } \frac{\text{(lbs./day)}}{\text{cu.ft.}}} \times \text{Digester vol. (cu.ft.)} = \text{Gas cu.ft./lb.} \ [\times 0.062 = \text{m}^3/\text{kg}]$$

11. Gas Produced in Pounds per Day

Find pounds of gas produced per day if pounds of raw sludge volatile solids are known.

a. Net volatile available for conversion = raw lbs. in – (dig. vol. remaining + lbs. lost in supernatant: NVS = VS raw (lb./day) – (dig. VS lb./day + super. VS (lb./day)

b. NVS (lb./day) × VS reduction (%) = Gas (lbs./day) [× 16.02 = kg/m^3]

12. Volume of Sludge Pumped (Approximate From Piston Pump Strokes)

Find volume of sludge to digester from piston pump operation.

a. Volume pump cylinder per inch times stroke in inches

$$\text{Vol. cu.in./in.} \times \text{stroke (in.)} = \text{Vol. sludge (cu.in.)} \ [\times 16.4 = \text{cm}^3]$$

b. Gallons per stroke

$$\frac{\text{Vol. sludge (cu.in.)}}{231 \text{ cu.in./gal.}} = \text{gal./stroke} \ [\times 3.79 = \text{l/stroke}]$$

c. Gallons sludge per day

$$\text{No. strokes (stroke/day)} \times \text{(gal./stroke)} = \text{sludge gal./day} \ [\times 3.79 = \text{l/day}]$$

13 Volatile Acids/Alkalinity Ratio (VA/Alk)

Find volatile acids/alkalinity ratio with both expressed as mg/l

$$\frac{\text{Vol. Acids (mg/l)}}{\text{Alk (mg/l)}} = \text{VA/Alk ratio}$$

14 Volatile Solids Ratio

Find the ratio of total solids in the digester to volatile solids in the feed

$$\frac{\text{TS in digester (lbs.)}}{\text{VS in raw sludge (lbs./day)}} = \frac{\text{TS}}{\text{VS/day}} \quad \text{(should be at least 10 for good digestion)}$$

(NOTE: See Metric Conversion Tables in Appendix D.)

APPENDIX G
DATA REVIEW AND GRAPHING

A number of tests have been recommended in this manual to provide process control information for digesters. The amount of information collected is of particular value if it is put to use for:

1. Day-to-day process control and routine preventive maintenance.
2. Making decisions to drain tanks.
3. Making decisions to repair equipment.
4. Providing consulting engineers with future design information.

Several books are available that assist the operator in methods for collecting and recording data. It is not the intent of this section to present those procedures. These publications include:

1. ***Operation of Wastewater Treatment Plants***, prepared by Sacramento State College, Chapter 16.
2. ***Manual of Wastewater Operations***, Texas Water Utilities Association (4th Edition), Chapters 28 and 29.
3. ***Manual of Practice No. 11***, WPCF, Chapters 19 and 22.
4. ***Simplified Lab Procedures for Wastewater Examination***, WPCF MOP No. 18.

There are several helpful systems developed by other operators that may be of value and these include methods of averaging, construction of graphs, use of graphs and use of solids balances.

MOVING AVERAGES

With some sets of figures that may change widely from day-to-day (such as sludge pumping or gas production), long-term moving averages are needed to establish trends. An example is given in Table G-1 to calculate a seven day moving average (DMA). When lab results are plotted on a graph as a 7 DMA, trends are easier to detect.

Table G-1
GAS PRODUCTION AVERAGE

2/1	12,300
2/2	14,700
2/3	11,000
2/4	11,500
2/5	14,600
2/6	15,800
2/7	12,500
	92,400 / 7
	13,200 = 7 DMA

Similarly, the 7 DMA for the next day 2/8 is the average of the previous six days starting with 2/2 and dropping 2/1 as shown in Table G-2.

Table G-2
GAS PRODUCTION AVERAGE

2/2	14,700
2/3	11,000
2/4	11,500
2/5	14,600
2/6	15,800
2/7	12,500
2/8	13,700
	93,800 / 7
	13,400 = next 7 DMA

The 7 DMA for 2/8 could also be calculated easily from the previous day's calculations by subtracting the data for 2/1 (12,300) from the subtotal on Table G-3 (92,400) adding the value of 2/8 (13,700) and dividing by seven.

Table G-3
7-DAY MOVING AVERAGE

Previous 7-day total (2/1-2/7)	92,400
Subtract day 2/1	12,300
Six-day total (2/2-2/7)	80,100
Add day 2/8	13,700
New 7-day total (2/2-2/8)	93,800
Divide by 7 to get average	/7
New 7 DMA	13,400 = 7 DMA

This method may be particularly useful in putting data together for percent volatile solids converted.

CONSTRUCTION OF GRAPHS

Placing columns of figures on graphs can show trends in information that will never be spotted when looking at monthly report forms.

The following example describes a plant that went through a period of high loading resulting in the need for corrective action. Previous episodes had occurred which resulted in long periods without adequate digestion and no gas production. By spotting the problem early, the corrections were made and failure was avoided.

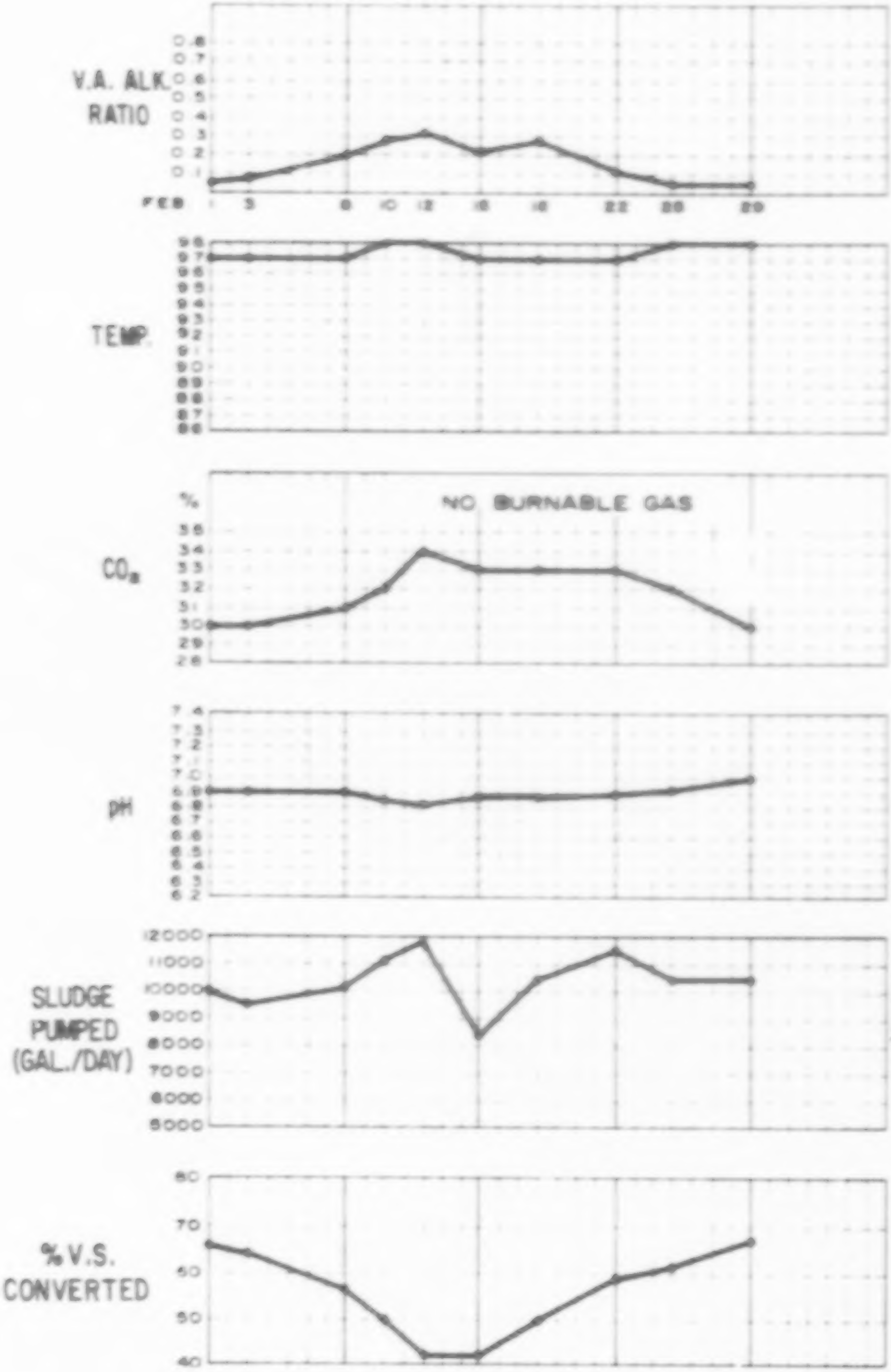
As an example of how graphs are constructed, the information on Table G-4 is plotted on the graphs shown on Figure G-1. As this example shows, the operator was able to prevent an extended upset by corrective action taken early, before the VA/Alk ratio went beyond 0.32. This was accomplished by adding 200 lbs. (91 kg) of soda ash on 2/10, 500 lbs. (227 kg) on 2/12 and 600 lbs. (272 kg) on 2/18.

One of the best uses of this type of a graph is to provide a history of what happened before, during and after a problem was corrected. Future operators at the plant can refer to the incident and use the action taken to prevent repeated upsets. The "Comments" column is very important. When anything unusual happens, it should be noted: without notes you won't know what happened, why, or what you did to correct it.

A blank form of this graph is also included in Appendix H.

Table G-4
PLANT MONTHLY REPORT—EXAMPLE

	VA mg/l	ALK mg/l	V/A	Temp $^{\circ}$F.	CO_2 %	pH	Sludge Pumped gpd	% Vol. Converted
2/1	120	2400	0.05	97	30	6.9	10,000	65
2/3	180	2300	0.08	97	30	6.9	9,300	62
2/8	450	2250	0.20	97	31	6.9	10,200	58
2/10	620	2200	0.28	98	32	6.85	11,200	50
2/12	900	2800	0.32	98	34	6.8	12,000	42
2/15	700	3200	0.22	97	33	6.85	8,200	42
2/18	950	3400	0.28	97	33	6.85	10,500	50
2/22	450	3700	0.12	98	33	6.9	11,600	59
2/25	200	3300	0.06	98	32	6.9	10,200	61
2/29	180	3000	0.06	98	30	7.0	10,200	66



COMMENTS

2/10 Added 200# Na_2CO_3
2/12 Added 500# Na_2CO_3
2/18 Added 500# Na_2CO_3

2/8 Raw sludge pumped began to increase.

FIGURE G-1
DIGESTER DATA GRAPHING EXAMPLE

SOLIDS BALANCE

F. J. Ludzack writes in the ***Operation of Wastewater Treatment Plants***, "What comes into a treatment plant must go out. This is the basis of the solids balance concept. If you measure what comes into your plant and can account for at least 90 percent of this material leaving your plant as a solid (sludge), liquid (effluent), or gas (digester gas), then you have control of your plant and know what's going on in the treatment processes. This approach provides a good check on your metering devices, sampling procedures, and analytical techniques. It is an eye opener when tried for the first time and advanced operators are urged to calculate the solids balance for their plant."

The results of the balance give the operator an idea of what is happening in his digester. If annual averages are used, the comparison between the calculated and actual should be within 10-15% of each other. If it is more than this, the accuracy of flow meters and lab results should be reviewed.

An example of the solids flow for the entire plant is shown on Figure G-2. Data for an individual plant could be shown on a similar drawing to give the operator a visual record of the overall operation.

Solids balance should be calculated once a year with the calculated results compared to the actual digester inputs and outputs.

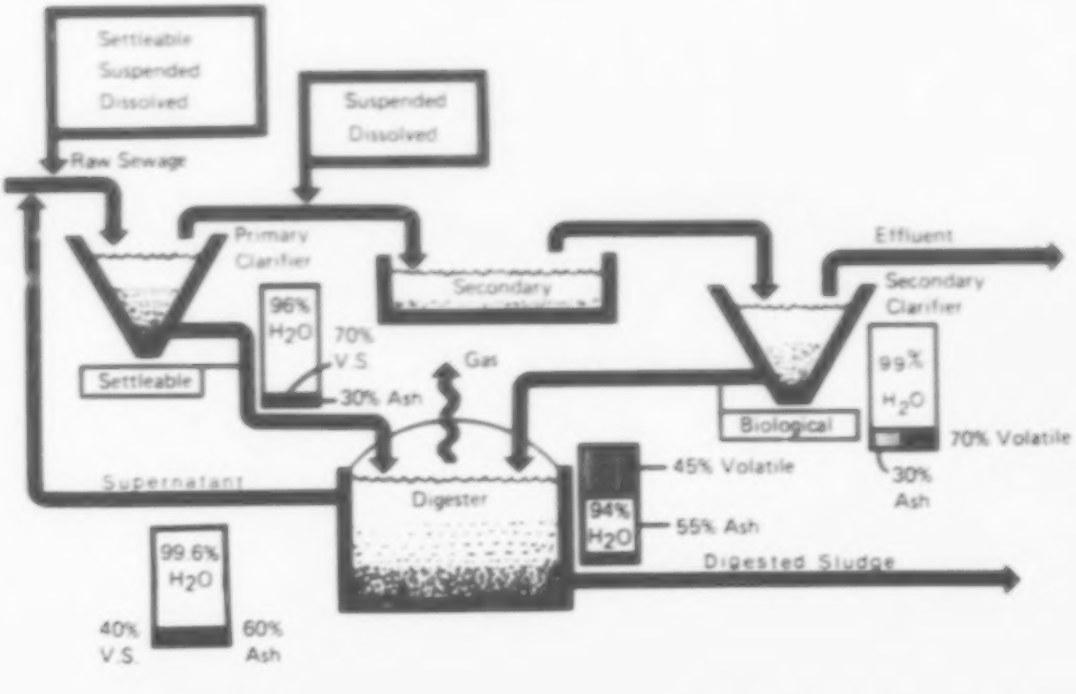

Settleable
Suspended
Dissolved
Suspended
Dissolved
Raw Sewage
Primary Clarifier
Secondary
Effluent
Secondary Clarifier
96% H2O
70% V.S.
30% Ash
Gas
Settleable
99% H2O
Biological
70% Volatile
30% Ash
45% Volatile
94% H2O
55% Ash
Supernatant
Digester
Digested Sludge
99.6% H2O
40% V.S.
60% Ash

FIGURE G-2
EXAMPLE OF A SLUDGE SOLIDS BALANCE

If the information shown in Table G-5 is known, a solids balance can be calculated. Averages over several months, or better, over the entire year, will give the most accurate results. The steps in making the calculation are shown on Table G-5 and a summary of the calculations appears on Table G-6. Figures shown in parentheses represent the number of the formula from pages F-1 and F-2.

Table G-5
INITIAL SOLIDS BALANCE DATA

	Raw	Digested	Supernatant	Gas
Quantity, gal/day	1,200	430		
Total Solids				
%	4.0	6.0	0.4	
lbs.	*(1)*	*(1)*		
Volatile Solids				
%	70	45	60	
lbs.	*(2)*	*(2)*	*(2)*	
Ash				
%	*(4)*	*(4)*	*(4)*	
lbs.	*(5)*	*(5)*	*(5)*	
Gas, lbs.				*(11)*

Note: gal × 3.785 = liters (l)

Using the information above, the following nine steps are used to fill in the missing information on Table G-6.

Step 1. Calculate the pounds of total solids in the raw sludge.

Step 2. Calculate the pounds of volatile solids in the raw sludge.

Step 3. Calculate the pounds of ash in the raw sludge.

Step 4. Calculate the pounds of total solids in the digested sludge drawn out.

Step 5. Calculate the pounds of volatile solids in the digested sludge drawn out.

Step 6. Calculate the pounds of volatile solids converted to other forms.

Step 7. Calculate the quantity of supernatant.

Step 8. Calculate the pounds of solids (total, volatile and ash) in supernatant.

Step 9. Calculate the pounds of gas produced.

The calculations are made using the formulas beginning on page F-1. These are summarized below and the answers are filled in on Table G-6.

1. Use Formula 1
   1,200 × 0.04 × 8.34 = 400 lbs. (182 kg)

2. Use Formula 2
   400 × 0.7 = 280 lbs. (127 kg)

3. Use Formula 6
   400 − 280 = 120 lbs. (55 kg)

4. Use Formula 1
   430 × 0.06 × 8.34 = 215 lbs. (98 kg)

5. Use Formula 2
   215 × 0.45 = 97 lbs. (44 kg)

6. Use Formula 8
   a. $\frac{0.7 - 0.45}{0.7 - (0.7 \times 0.45)} \times 100\% = 65\%$
   b. 280 × 0.65 = 182 lbs.

7. Difference between raw in and digested out
   = 770 gals. (2900 l)

8. Use Formulas 2, 4 and 5
   25, 15 and 10 lbs. (11, 7 and 4 kg)

9. Use Formula 11
   280 − (97 + 15) = 168 (77 kg)

Table G-6
FINAL SOLIDS BALANCE DATA

	Raw	Digested	Supernatant	Gas
Quantity, gal./day	1,200	430	770	
Total Solids				
%	4.0	6.0	0.4	
lbs.	400	215	25	
Volatile Solids				
%	70	45	60	
lbs.	280	97	15	
Ash				
%	30	55	40	
lbs.	120	118	10	
Gas				
lbs.				168

Note: *gal. x 3.785 = l*
lbs. x 0.454 = kg

The practical use of the information in Table G-6 would be to compare the results obtained in the solids balance with the average for three or four winter months or a period of the year when industrial wastes may affect digester operation.

For example, one plant that received high amounts of vegetable wastes during the summer found that raw sludge dry solids content reduced while total volatile solids to the digester increased. Gas production increased, but volatile reduction decreased because detention time in the digester decreased. The plant had to install sludge thickening facilities to solve the problem.

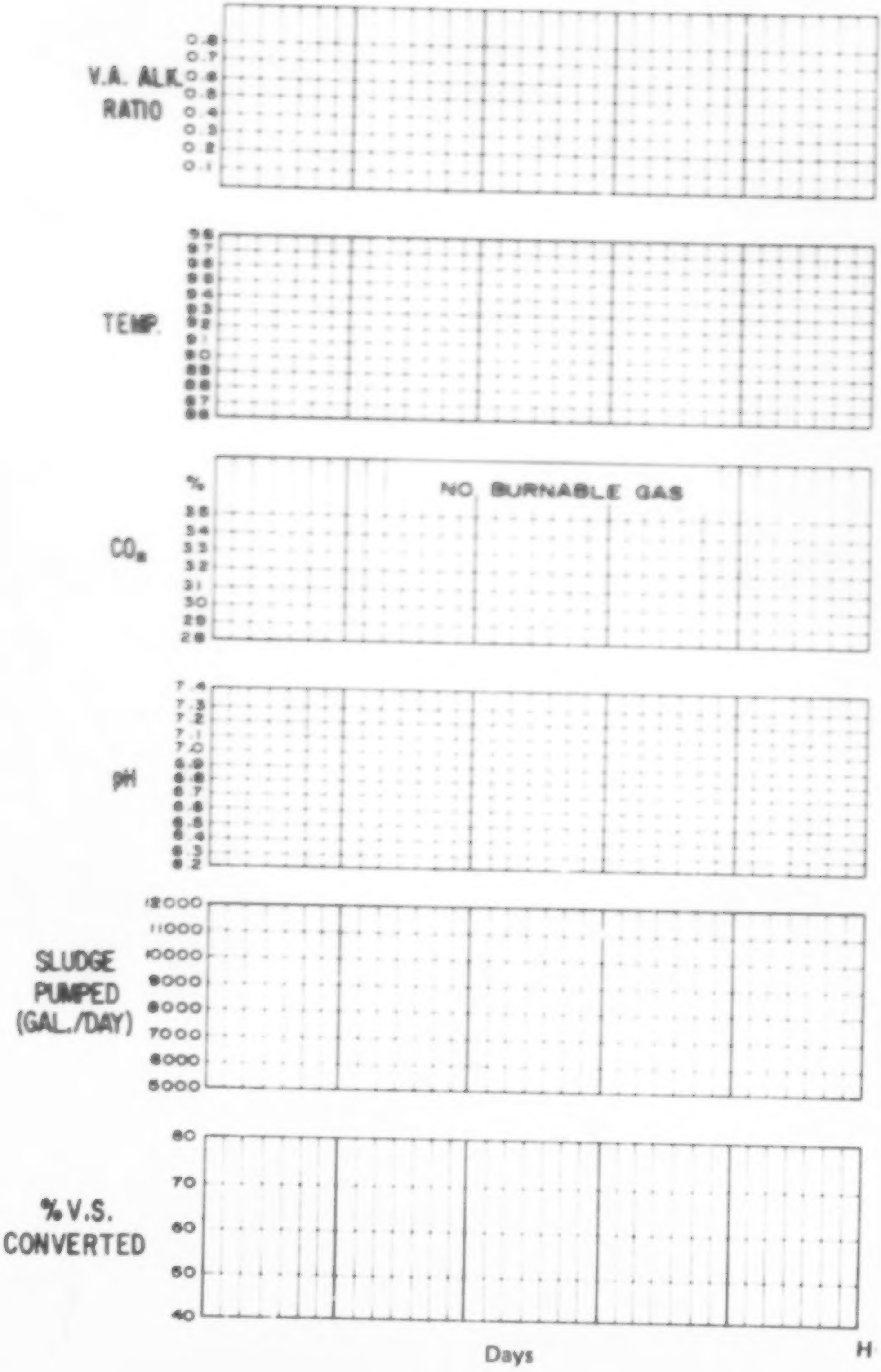
Table G-7 summarizes the information from this plant.

Table G-7
PLANT DATA SUMMARY

	Raw	Digested	Supernatant	Gas
Quantity, gal./day	2,600	930	1,670	
Total Solids				
%	2.5	3.8	0.6	
lbs.	542	294	84	
Volatile Solids				
%	78	62	65	
lbs.	423	182	55	
Ash				
%	22	38	35	
lbs.	119	112	29	
Gas				
lbs.				186

APPENDIX H
WORK SHEETS

COMMENTS



PLANT REVIEW CHECK LIST PART I

INSTRUCTIONS

1. Column A – Mark number of units or X whichever applies in yes column for equipment on site
2. Column B – Use engineering data in O & M Manual and write in design information
3. Column C – Write in actual plant values
4. Column D – Make a comparison between Columns B and C and mark X in appropriate D column
5. Column E – Mark X in appropriate column
6. Column F – Comments

	A		B	C	D		E		F
	Yes	No	Design Size or Capacity	Comparison or Measurement	Adequate	Not Adequate	Is An Alternate Available Yes	No	Comments
TYPE OF DIGESTION PROCESS									
A. Single Stage									
1. Unheated (unmixed) Loading 0.03 to 0.10 lbs. of VS/cu ft/day									
2. Heated (mixed and unmixed) Loading 0.03 to 0.10 lbs. of VS/cu ft/day									
B. Two Stage									
1. Conventional Loading 0.03 to 0.10 lbs. of VS/cu ft/day									
2. High Rate Loading 0.10 to 0.40 lbs. of VS/cu ft/day									
C. Results									
1. Overloaded									
2. Underloaded									

PLANT REVIEW CHECK LIST – PART II

INSTRUCTIONS

1. *Column A – An X in the Yes column shows plant is doing something or answers a question.*
2. *Column B – Indicate from engineering data appropriate information.*
3. *Column C – Write in actual average data.*
4. *Column D – Compare Column C with initial column data and mark an X in appropriate D column.*
5. *Column E – Indicate whether plant has an alternate available.*
6. *Column F – Comments.*

	A		B	C	D		E		F
	Yes	No	Design Size or Capacity	Comparison or Measurement	Adequate	Not Adequate	Is An Alternate Available Yes	No	Comments
III. OPERATING PROBLEMS									
Are there problems affecting the operation of the plant?									
A. Sludge Feed Schedule									
1. Continuous									
2. [illegible]									
B. Is the feed [illegible]									
1. Primary sludge [illegible]									
2. Waste activated sludge [illegible]									
3. Trickling filter humus [illegible]									
4. Combined primary sludge and waste activated sludge 4%									
5. Combined primary sludge and trickling filter humus sludge 4%									
C. Supernatant									
1. Total Solids – Weekly less than [illegible]									
2. Volume returned [illegible]									
D. History of Extreme Loadings									
1. Flow									
2. Organic									
3. Inorganic									
4. Toxic									
E. Extreme Weather Conditions									

[illegible]

Note: Normal ranges and frequencies are noted

A. [illegible]

[illegible]

4. Temperature, daily
   a. Feed sludge [illegible]
   b. Digester [illegible]

5. pH, daily
   a. Feed sludge [illegible]
   b. Digester [illegible]

6. [illegible] daily
   a. Digester [illegible]

[illegible]

7. Volatile [illegible]
   a. Feed [illegible]
   b. Digester [illegible]
   c. Digested [illegible]

V. PERSONNEL
A. Is the staff [illegible]

B. [illegible] qualified

C. [illegible]

VI. TANK CONDITION
A. Cover
   1. Leaking
   2. Damaged

B. Structure
   1. In good condition
      a. Walls
      b. Floor

C. Contents
   1. Thick scum layer
   2. Thick grit layer
   3. Foaming